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Depositional environments and petrology of the Fort Union formation near Livingston Montana: An evaluation as a host for sandstone type uranium mineralization

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DEPOSITIONAL ENVIRONMENTS AND PETROLOGY OF THE FORT UNION FORMATION
NEAR LIVINGSTON, MONTANA: AN EVALUATION AS A HOST FOR
SANDSTONE TYPE URANIUM MINERALIZATION

By

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ABSTRACT

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Depositional Environments and Petrology of the Fort Union Formation Near Livingston, Montana: An Evaluation as a Host for Sandstone Type Uranium Mineralization (84 pp.)

Director: Ian Lange

The Fort Union Formation in the western Crazy Mountain basin is a syntectonic series of coalessing alluvial fans, deposited by southeast flowing streams during latest Cretaceous and the Paleocene. Four sedimentary facies were recognized: an apical conglomeratic-braided stream facies, a coarse-grained meanderbelt facies, a delta topset facies and a distal bar-finger sand-distributary channel facies. Detritus consists mainly of andesitic Elkhorn volcanic clasts plus minor Precambrian basement and Paleozoic sedimentary rock fragments.

The Fort Union coarse-grained meanderbelt facies is similar to uranium-bearing sandstones of the Wyoming Basins and Colorado Plateau. Three possible uranium sources for sandstone mineralization, include the Elkhorn volcanics, the Crazy Mountains alkaline intrusives and a Tertiary tuff which may have overlain these strata. Diagenetic conditions were slightly alkaline and reducing based on the occurrence of authigenic clinoptilolite and the preservation of carbonaceous debris.

Based on the limited amount of highly weathered exposures the economic potential of the Fort Union is not fully known. Although many favorable characteristics for the occurrence of uranium are present within the Fort Union, scintillometer readings and surface water uranium contents are low. Extensive use of radiometrics and drilling will be necessary in future exploration efforts.

ACKNOWLEDGMENTS

Many thanks to Dr. Ian Lange for steering me toward this project and visiting the study area. I am deeply indebted to Dr. Johnnie Moore for the encouragement, guidance and time he contributed to this study. Dr. Don Winston and Dr. Gray Thompson helped me gain the background knowledge required for the project. Special thanks to my parents who encouraged me throughout my education. Field expenses were covered by a grant from the Los Alamos Scientific Laboratory and Bendix Field Engineering. Geochemical analyses were provided by the Los Alamos Scientific Laboratory.

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CHAPTER I

INTRODUCTION

Numerous studies show that the demand for uranium in the United States will be significantly higher than the U.S. production through the year 2000 (National Academy of Sciences, 1975). This situation has resulted in intensified exploration for new uranium reserves.

Sandstone-type uranium deposits account for 90 percent of the United States reserves and potential resources (Hetland, 1976). The majority of these deposits are located in approximately fifteen small districts in the Colorado Plateau and Wyoming Basins, and despite intensive exploration in the United States, no other major uranium deposits have been discovered. Many of the sandstone-type uranium roll-front deposits exploited today are close to the surface and were easily located by radiometric surveys. Deeply buried uranium deposits have little if any surface radiometric expression, necessitating more elaborate exploration efforts. While the quest for more sophisticated instrumentation continues, the present search for additional roll-front deposits will only be successful if based on the genetic models of known districts.

Genetic Model

Sandstone uranium deposits are strata-bound, epigenetic impregnations formed by supergene fluids. Uranium minerals fill host rock pores, replace sand grains, cementing materials and plant fossils (Fisher, 1974). Intimately associated with these deposits are zones of pervasive oxidation and bleaching of the host rock updip from the ore body (Fig. 1). Typically, these deposits range in size from a few tons to a million tons of ore with an average grade of 0.15% U_3O_8 (DeVoto, 1978).

In an excellent review of sandstone-type uranium mineralization, Rackley (1976) argues that most if not all of the host rocks shared a common tectonic, sedimentation and diagenetic history (Table 1). The formation of a typical uranium host rock begins with the uplifting of a source area containing "granitic" intrusives, far removed from the continental margin. Concurrent with uplift volcanic centers may become active, contributing ash and stream worn detritus. The increase in stream gradients from the uplift enables coarse clastics to be transported. When sediment laden streams reach basins adjacent to the uplifted area, rapid deposition occurs due to the abrupt decrease in stream gradients. Repeated deposition builds up a series of coalessing alluvial aprons, which prograde across the basin. Sedimentation on the apex of the fan, proximal to the mountain front, may be dominated by coarse-grained, high-energy, tractive-load braided streams. Further from the mountain front lower stream gradients favor fine grained meanderbelt systems (Brown, 1973; Fig. 2). Suspended load deposition predominates on the more distal portions of the apron. The resulting sedimentary pile consists of a series of lenticular conglomerates and carbonaceous sandstones, interfingered with mudstones; a sequence with highly variable porosity and permeability.

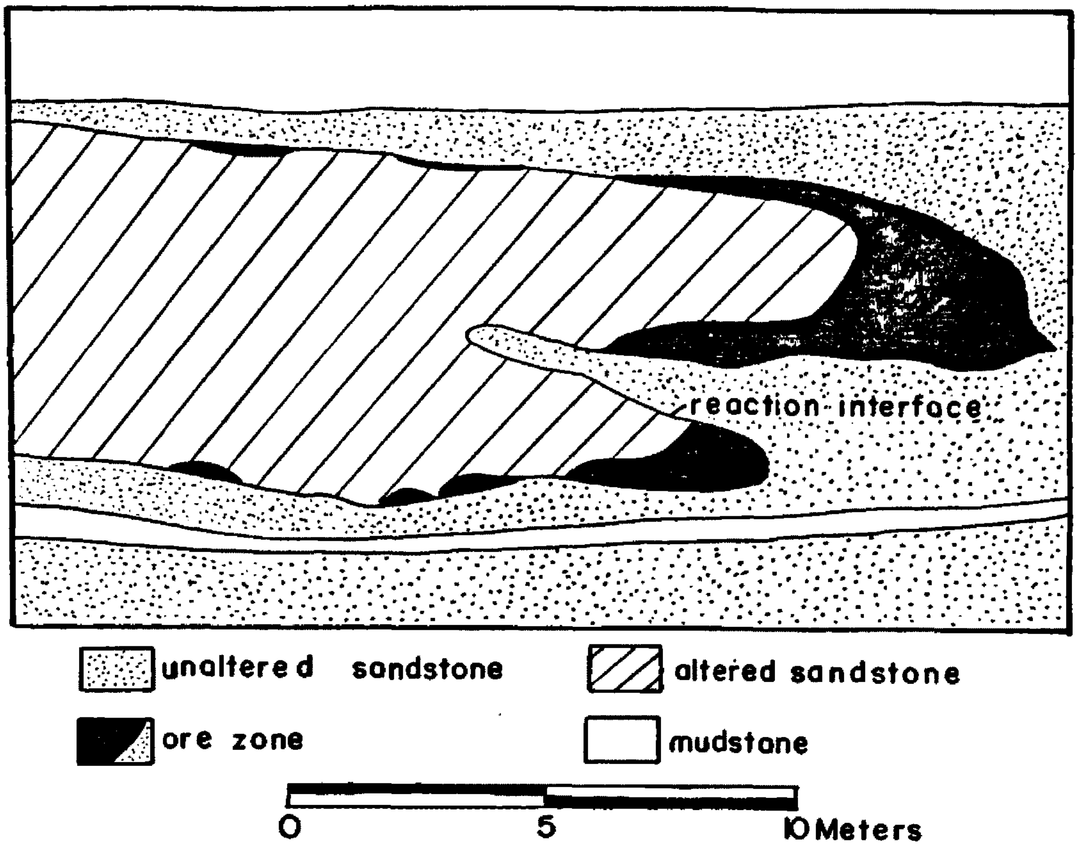

Figure 1 Cross section through a typical uranium roll front.

CONTENT OF URANIUM ROLL DEPOSITS

	oxidized rock	ore zone	unaltered rock
Pyrite	diminished	strongly increased	present
Uranium	slightly increased	strongly increased	present
Molybdenium	slightly increased	strongly increased	present
Selenium	slightly increased	strongly increased	present
Vanadium	slightly increased	strongly increased	present

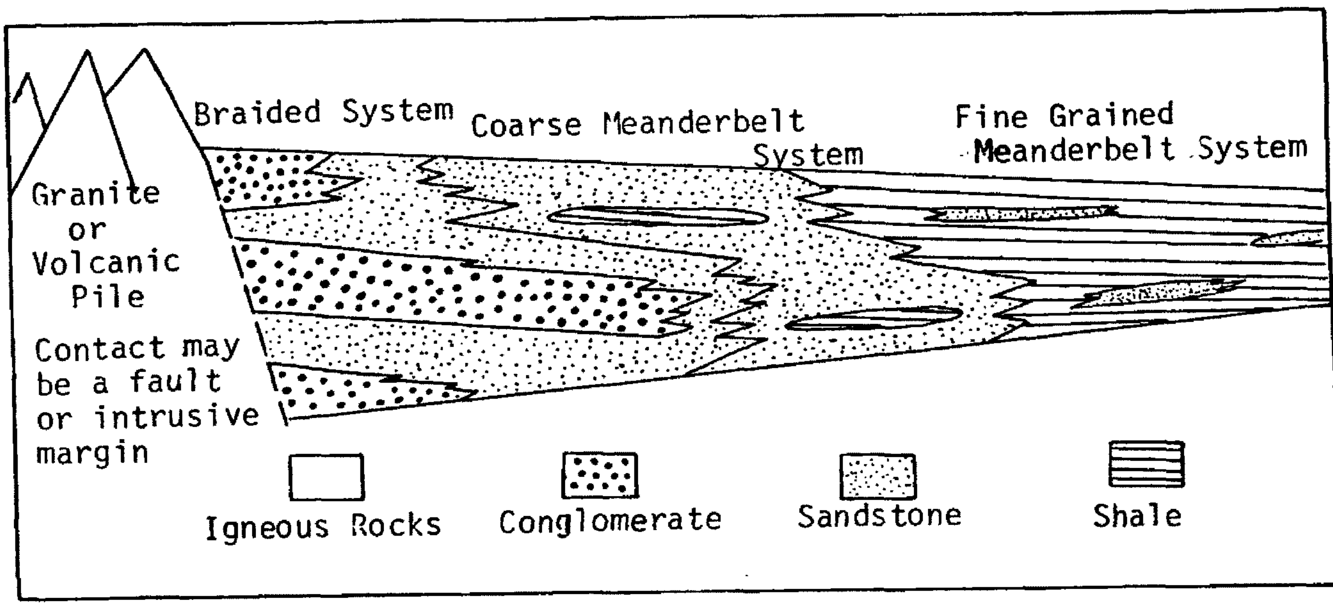

Figure 2 Idealized Cross-Section of An Alluvial Apron

Table 1. Common features of sandstone-type uranium deposits (from Rackley, 1976)

A. Tectonic conditions

1. Host rock is part of a thick, extensive sequence, much of which may be red beds

2. Host rock is feldspathic, micaceous or cherty sandstone

3. Volcanic material is present in or overlying the host rock

4. Upstream erosion of host rock

5. Burial and preservation

B. Sedimentation

1. Sedimentation by stream flow of braided or meandering streams on local or regional unconformities

2. Sandstones and conglomerates tend to be lenticular and relatively restricted

3. Siltstone and mudstone are interbedded with and in erosional relationship to sandstones and conglomerates

4. Mudstone clasts are common constituents of sandstone and conglomerates

C. Sedimentary environment, paleoclimate and diagenesis

1. Light gray or green to dark gray sandstones with gray and green mudstone, all commonly pyritic; pink or red mudstones present but minor in amount

2. Gypsum crystals in mudstones

3. Reptilian fauna

4. Bioturbation

5. Vegetal carbonaceous material from logs, stumps and roots in place, detrital fragments to bacterial residue and/or asphaltic material

Table 1 (Continued)

D. Mineralization and Alteration

1. Uraninite and coffinite are principal uranium minerals, in non-weathered deposits
2. Mineralization is both discordant and concordant with sedimentation
3. Mineralization occurs in sharp contact with carbonaceous-free or oxidized zones
4. Epigenetic minerals occur in same relative spatial positions when present
5. Mineralization is most common in thicker sandstone-facies belts where mudstone facies make up 20-50% of the sequence.

Recurrent uplift in the source area will prograde wedges of coarse clastics over finer grained sediments. If the source area becomes tectonically stable the processes of erosion and sedimentation will eventually establish a graded profile. This condition causes deep weathering which releases dissiminated uranium from source materials. In the depositional basin a graded profile leads to the establishment of vegetated, reduced overbank deposits.

The formation of a uranium deposit begins with the uplifting and erosion of a porous and permeable sandstone. Most uranium districts tend to be restricted to narrow belts that wrap around centers of Cretaceous and Tertiary uplifts and igneous intrusives of various ages (Gabelman, 1971). Oxygenated surface waters flow from the outcrop, down the structural and/or depositional dip of the reduced channel sandstones, forming a continuous three dimensional body of oxidized sandstone (geochemical cell, Rackley, 1976). Uranium, leached from granites, devitrified tuffs and the up-dip oxidized sandstone is transported as a carbonate complex in the U^{+6} oxidation state (Garrels, 1957; Hosteller and Garrels, 1962). When uraniferous solutions encounter organic debris and/or H_2S, soluable U^{+6} ions are reduced to U^{+4} and precipitated as uraninite possibly with the aid of bacteria (Breger, 1974; Jensen, 1958, 1963). Precipitation occurs at the margin of the expanding geochemical cell in a zone termed the reaction interface (Fig. 1). Uranium is continuously precipitated and dissolved on the "upstream" side of the interface and reprecipitated down-dip as the geochemical cell expands. Ultimately when equilibrium is established the cell no longer expands and uranium "rolls" are left as small isolated bodies separated by enormous barren intervals (Fig. 3). These uranium deposits must be isolated from continued oxidation and erosion in order to be preserved. Preservation is insured by the deposition of impermeable strata above the host.

After burial the uranium deposit may have very little surface radiometric expression. The exploration geologist must determine the sedimentological history of the basin and with the aid of geophysical data, choose favorable drilling sites. If the hole penetrates the barren interior of a geochemical cell further drilling, down dip is required to locate the reaction interface. Extensive drilling is required to outline the geometry of the geochemical cell and to determine uranium reserves.

The simplified model presented above cannot explain the genesis of many uranium districts. Deposits below unconformities in the Chinle formation (Utah) may have formed by the vertical development of a geochemical cell, concurrent with weathering (Rackley, 1976). Uranium deposits along the Texas coast apparently formed in fluvial and marine sandstones proximal to fault zones which supplied H_2S derived from deep hydrocarbon reservoirs (Eargle et. al., 1975). Faulting has also influenced the shape and location of uranium "stack" deposits of the Colorado Plateau. There is also disagreement over the source of uranium ions, transporting fluids and the timing of mineralization. However, the generalized working model, with its many variations, provides a basis

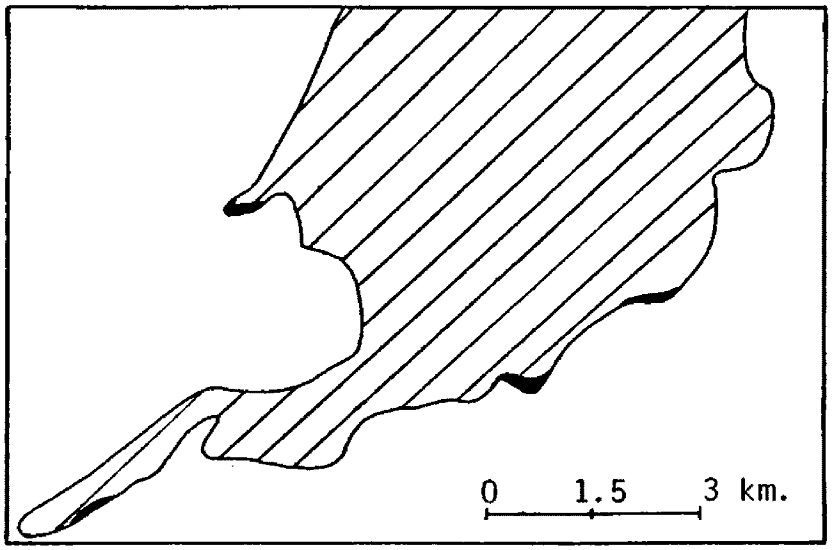

Figure 3 Plan View of A Typical Geochemical Cell

Oxidized Sandstone

Uranium Ore Body

modified from Harshman, 1974

for the selection of new exploration targets in untested sedimentary basins.

Purpose of This Study

After reviewing the literature on the Fort Union Formation in the western Crazy Mountains Basin (Fig. 4), it was apparent that these clastic rocks contain many of the requisites listed in Table 1. Because the Fort Union appeared favorable for uranium concentration, the sedimentology and petrology of this formation was investigated for the purpose of evaluating its potential as a uranium bearing host rock.

Field work was conducted during the summer of 1978. The easily weathered Fort Union sediments support heavy grass, sage and forest cover. Bedrock is exposed in about 5 percent of the study area. Siltstones and mudstones outcrop only in stream and road cuts. Resistant conglomerates and sandstones outcrop except where the structural dips are less than 10 degrees. Crucial relationships between coarse-grained clastic rocks and fine-grained mudstones are seldom exposed. Because of the extensive cover, stratigraphic sections were not measured. Sedimentologic observations and samples for laboratory examination were collected from outcrops along Area Creek, Brackett Creek and the Shields River (Fig. 5). Vertical stratigraphic control varies from good to very poor. Lateral stratigraphic control is generally poor due to the paucity of persistant marker beds.

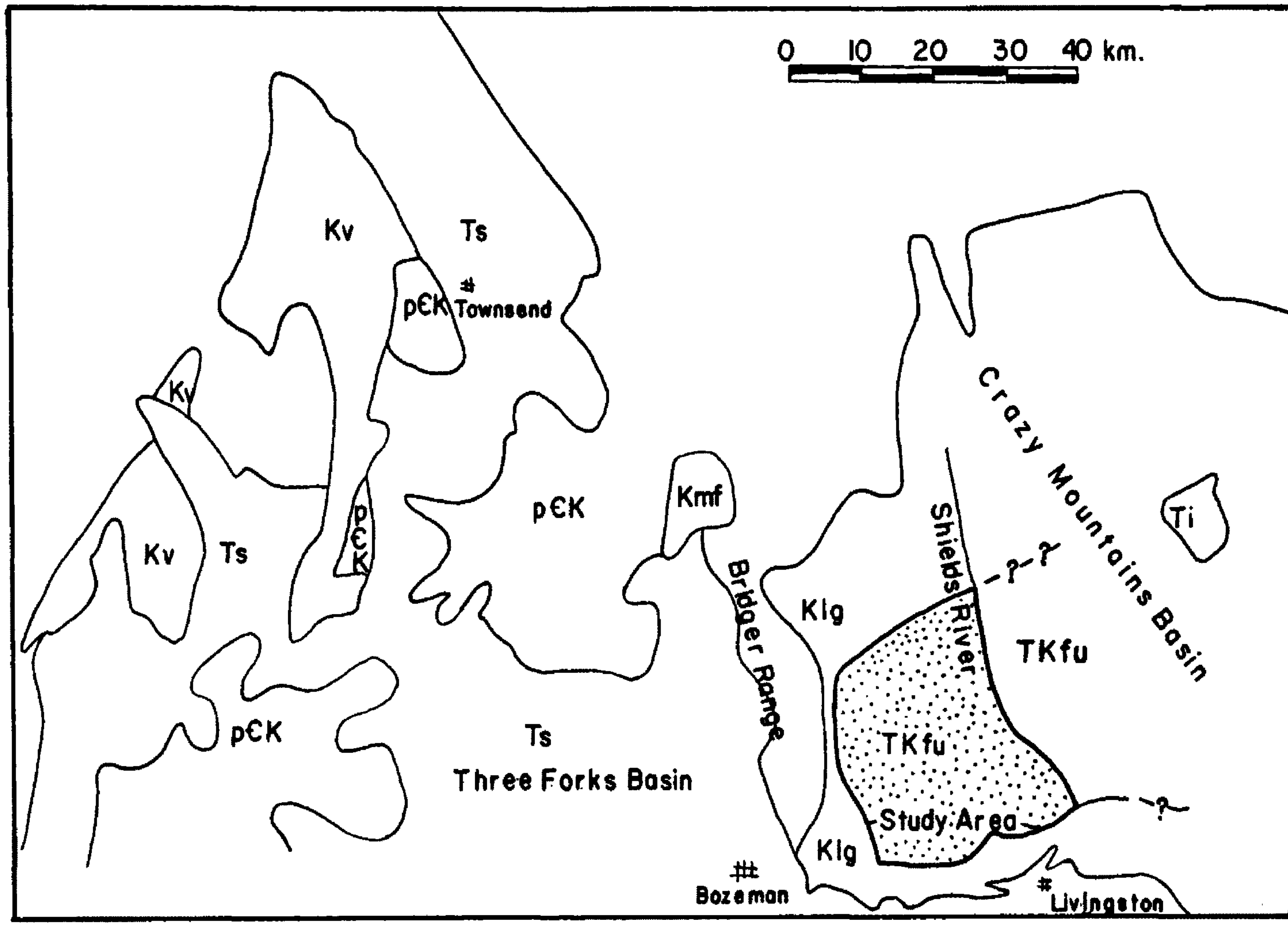

Figure 4 Location map. Ts=Tertiary sediments, TKfu=Fort Union Formation, Klg=Livingston Group, Kmf=Maudlow volcanics, Kv=Elkhorn volcanics, pЄK=Precambrian through Cretaceous undifferentiated, Ti=Tertiary intrusives. Stippled pattern denotes study area.

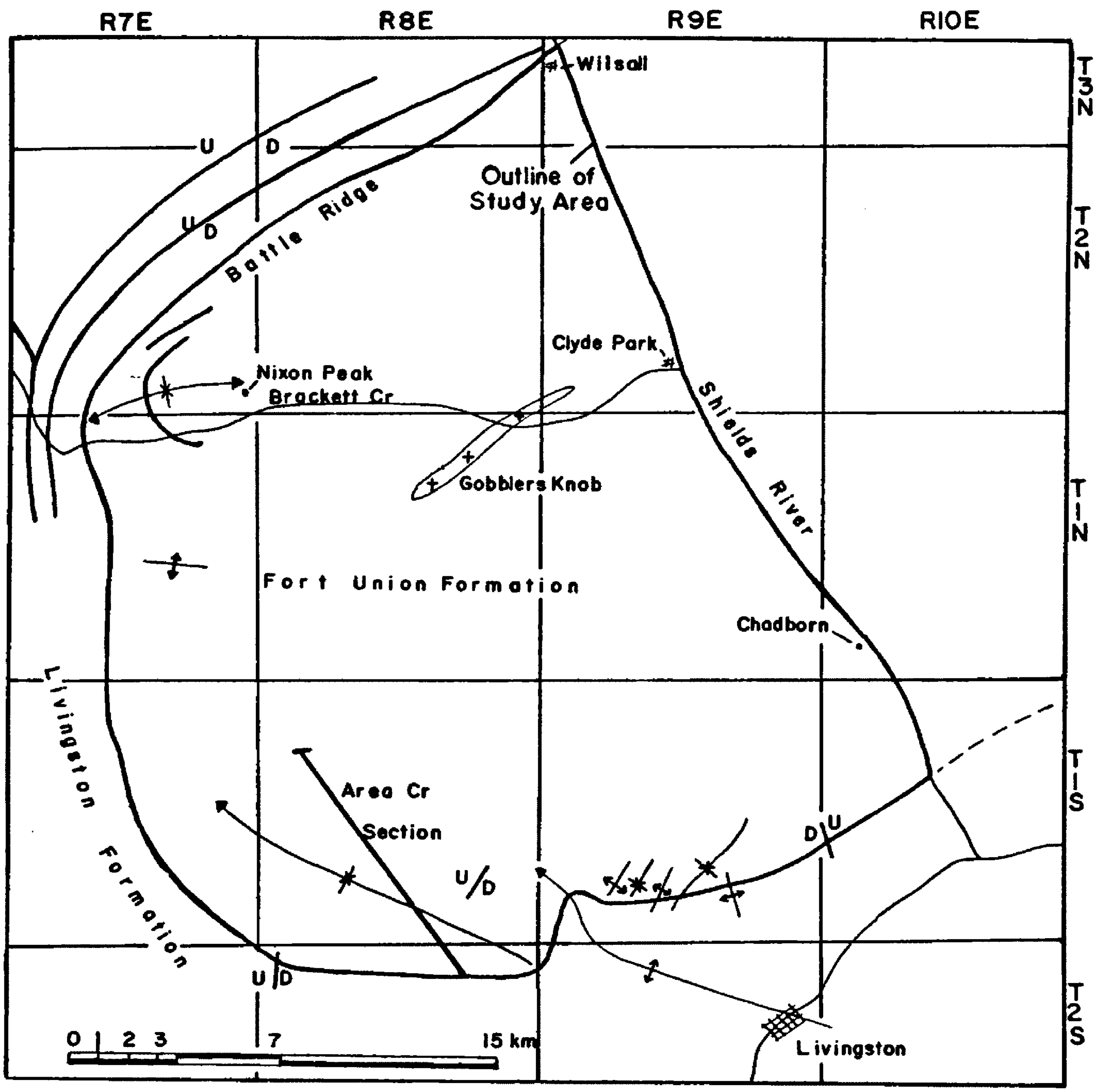

Figure 5 Structural map of the study area. Structure from air photos and Roberts,(1972), plate 3.

Previous Work

Strata of the Crazy Mountains Basin were first examined by Weed (1893). He assigned the name Livingston Formation to the thick volcaniclastic sequence overlying the Laramie Formation, the top of which is now the Eagle Sandstone. Weed recognized the polylithic nature of the Battle Ridge conglomerates and stated: "There is some evidence that may prove sufficient cause for a separation of these conglomerates and silts from the Livingston Formation and their recognition as the base of the Fort Union Group." Later workers acknowledged this possibility (Stone and Calvert, 1910; McMannis, 1955). However, the solution to the complex stratigraphy was often compliated by the arbitrary application of the name Livingston to a wide variety of volcanic and sedimentary units (Skipp and McGrew, 1977).

Roberts (1963, 1972) defined the Livingston Group and subdivided it into four formations on the basis of mollusks, vertebrates and rock type. Roberts also defined the Fort Union Formation in the Crazy Mountains Basin as those sediments overlying the Livingston Formation, containing detritus derived from basement rocks and Paleozoic sediments, and marked by a basal conglomerate. Roberts (1972) recognized heavy mineral suites that were derived from basement rocks exposed during the deposition of the Livingston. However, he suggested the limited quantities of sillimanite, corundum and staurolite in the Livingston were derived from smaller, less elevated basement exposures than during the time of Fort Union deposition.

Weed (1893) recognized a brackish and fresh water fauna within the Livingston and Fort Union Formations. Based on this faunal evidence and the correlation of the Livingston with marine beds of the Claggett, Judith River, Bearpaw, Lennep and Hell Creek Formations, Stone and Calvert (1910) suggested the Livingston to be a transistional marine deposit (Fig. 6). In a detailed sedimentological study, Sims (1967) subdivided the Livingston Group into three new formations and interpreted it as a flood plain-delta complex, deposited by northeastward flowing streams.

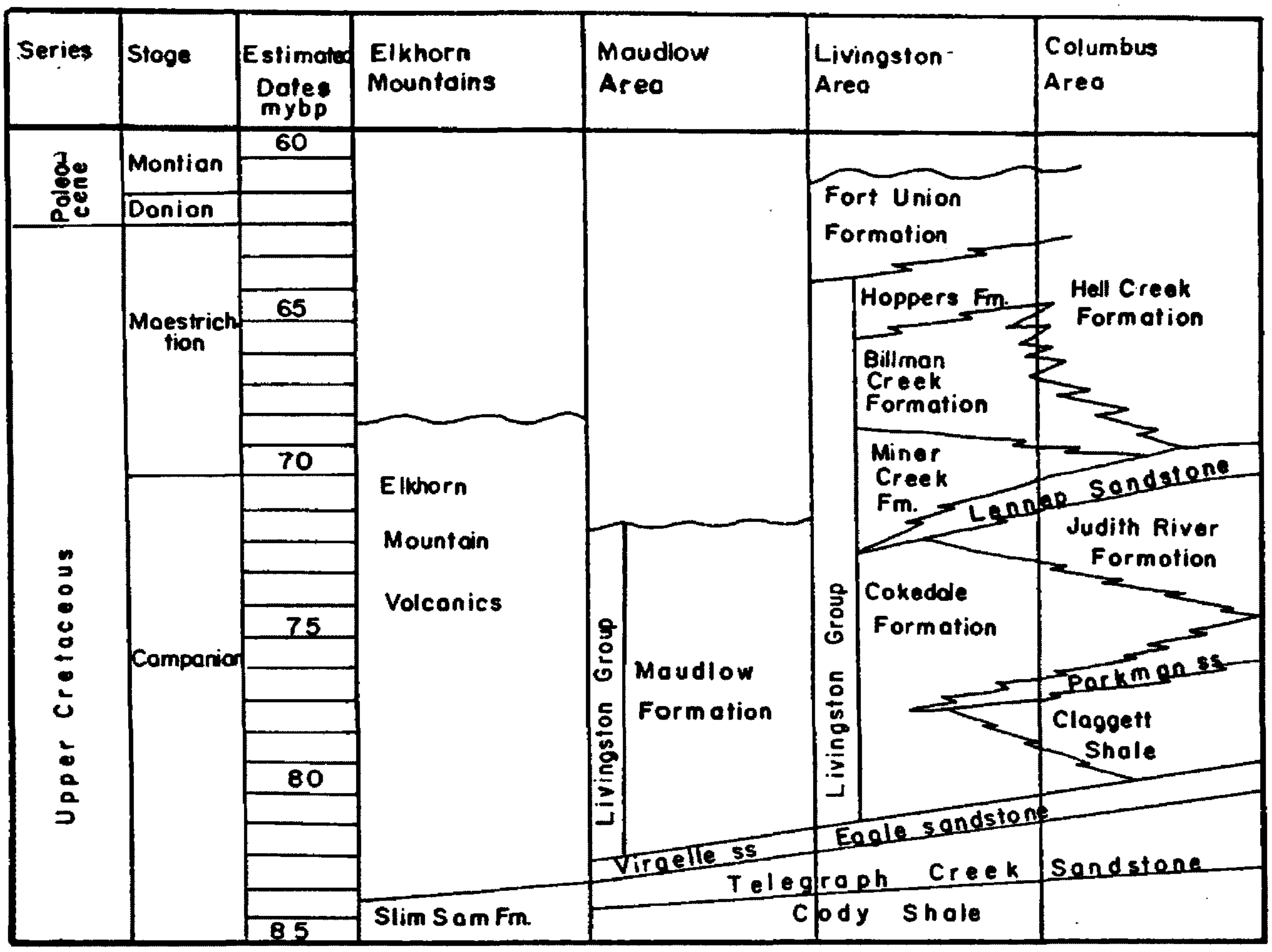

Figure 6 Correlation chart showing relationships of Upper Cretaceous and Paleocene strata in Central Montana. Modified from Roberts (1972) and Skipp and McGrew (1977).

CHAPTER II

REGIONAL SETTING

Geologic History

The oldest rocks in the Livingston area are the Precambrian metamorphic schists and gneisses exposed in the Bridger and Beartooth Mountains, the source for late Precambrian Beltian sediments deposited northwest of the study area (Winston, 1977). During the Paleozoic, Central Montana was the site of epicontinental marine mud and carbonate deposition (McMannis, 1965). These marine deposits were then sub-aerially exposed and locally overlain by terrestrial sands of the Triassic Chugwater Group (MacLachlan, 1972). Early Jurassic seas transgressed this continental environment, depositing sands, muds and carbonates of the Ellis Group. Late Jurassic and early Cretaceous terrestrial sediments of the Morrison and Kootenai Formations prograded over earlier marine deposits in much of Central Montana. The basal conglomerate of the Kootenai Formation indicates strong uplift occurred west of Montana (McMannis, 1965). The extensive early Cretaceous epicontinental sea transgressed continental environments depositing marine sands and muds of the Colorado Group throughout Central and Eastern Montana.

Approximately 83 m.y.b.p. volcanic centers in Central Montana extruded the Elkhorn Mountain, Wolf Creek and Livingston Igneous Series (south of Big Timber) (Skipp and McGrew, 1977). As volcanism continued the Cretaceous sea retreated to the east and the Crazy Mountains Basin was downwarped (Roberts, 1963). Concurrent with volcanism and downwarping volcaniclastic sediments of the Livingston Group were deposited in the western portion of the basin (Roberts, 1972, Skipp and McGrew, 1977). The deltaic Livingston Formation thins and interfingers with marine sediments of the Montana Group east of the Crazy Mountains (Sims, 1967). During latest Cretaceous and Paleocene, the Fort Union Formation was deposited throughout the Crazy Mountains Basin (Roberts, 1972). Similar thick synorogenic coarse clastic sequences were deposited in localized basins in Western Montana and Wyoming at this time. The Fort Union, Livingston, Beaverhead, Golden Spike, Sphinx Mountain and Harebell Formations record the sedimentary history of extensive Laramide uplift in the Northern Rockies (Ryder and Scholten, 1973; Gwinn and Mutch, 1965).

Approximately 58 m.y.b.p. alkaline and calc-alkaline hyperbyssal dikes, sills and laccoliths of the Crazy Mountains Series intruded the central portion of the basin (Larsen and Simms, 1972). There is much speculation on the genesis of these intrusives; present tectonic models are unable to correlate the Montana alkaline series with the Eocene subduction zone in Western Washington and Oregon (Burchfield and Davis, 1975).

Currently Southwest Montana is seismically active (Smith and Sbar, 1974) and the Livingston area is the site of active erosion.

Regional Structure

The Crazy Mountains Basin is a structural depression created during the late Cretaceous (Roberts, 1963). The basin is bounded on the north by the Castle Mountains, on the west by the Bridger Range and Big Belt Mountains, on the south by the Beartooth Range and the Nye-Bowler Lineament and on the east by the Pryor-Big Horn uplift (Fig. 7). Tectonically the Crazy Mountains Basin is located on the cratonic site of the foreland thrust belt and is therefore classified as a retroarc basin.

The structural pattern of the Crazy Mountains Basin is a result of the superposition of Laramide compression on previously fractured basement rocks (Garrett, 1972). Garrett hypothesized that structures northwest of Battle Ridge are generally related to thrusting while structures southeast of Battle Ridge resulted from dip slip and transcurrent basement movements. Laramide compression induced reverse movement along a high angle Precambrian fault, forming the Battle Ridge monocline (Fig. 8). Just north of the Battle Ridge fault zone coarse arkosic Belt Supergroup rocks occur suggesting this to be the northern edge of the Dillon Block (McMannis, 1955, Winston, 1977).

The Bridger Range, located west of the basin, is an eastward thrust block of Precambrian and Paleozoic rocks. Uplift began during the late Cretaceous but thrusting did not occur until after Fort Union deposition (McMannis, 1955). This thrusting folded the Livingston and Fort Union strata to a near vertical orientation along Bridger canyon. East of

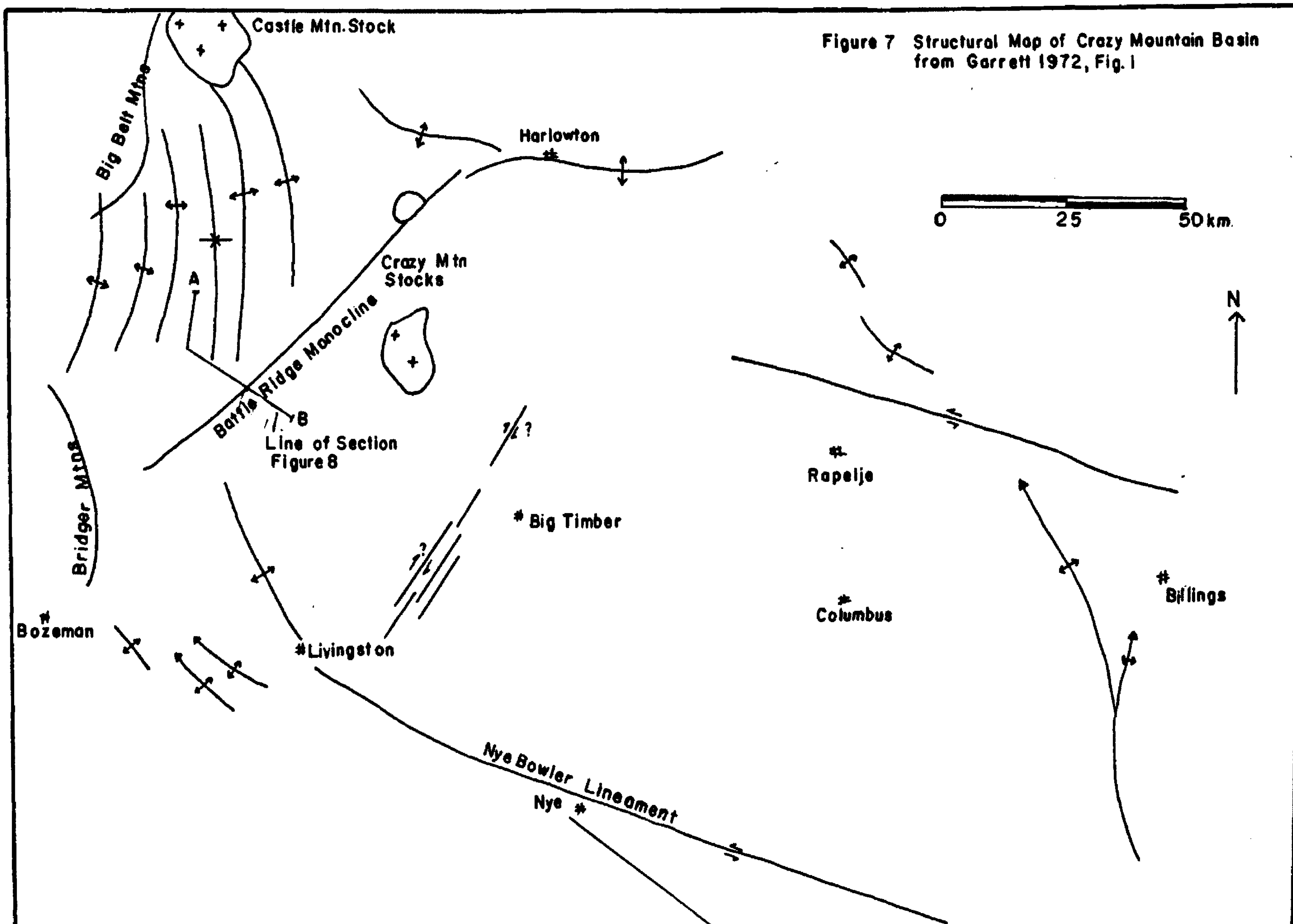

Figure 7 Structural Map of Crazy Mountain Basin from Garrett 1972, Fig. 1
Castle Mtn. Stock
Big Belt Mtns
Harlowton
0
25
50 km.
N
Crazy Mtn Stocks
Battle Ridge Monocline
A
B
Line of Section Figure 8
Bridger Mtns
Rapelje
Big Timber
Billings
Columbus
Bozeman
Livingston
Nye Bowler Lineament
Nye

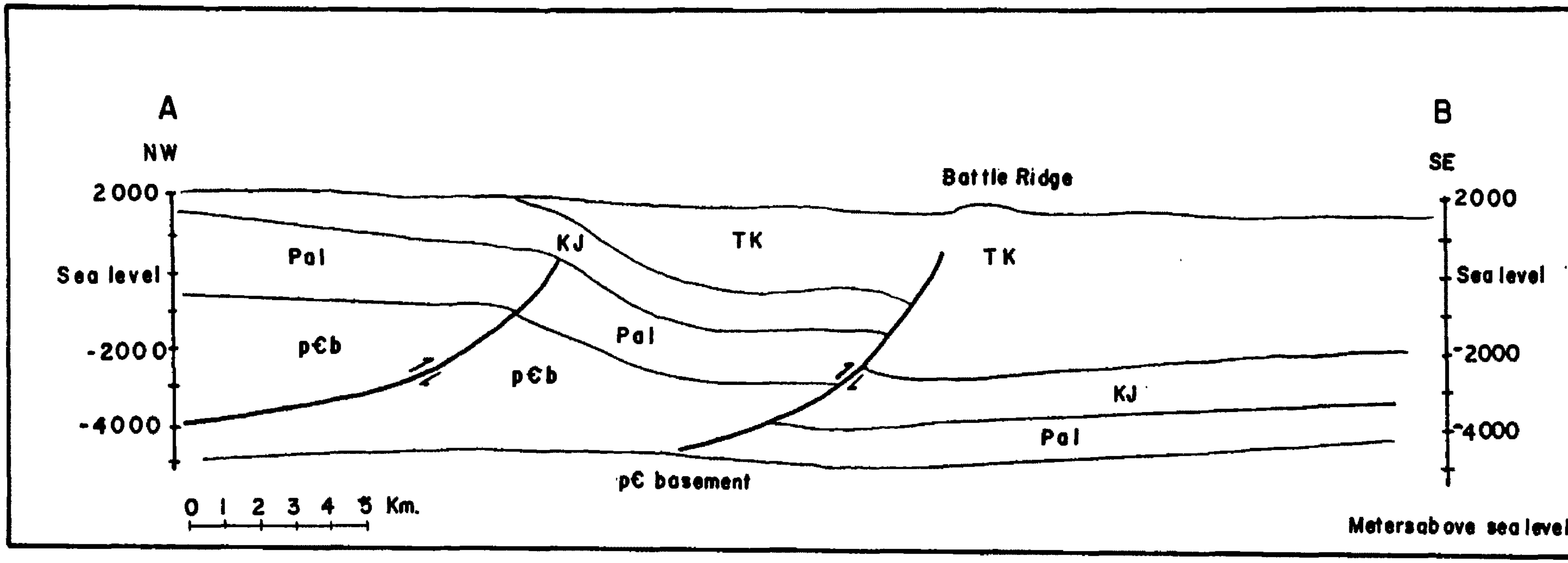

Figure 8 Cross-section through Battle Ridge Monocline. Line of section A-B shown on Figure 7. TK= Fort Union Formation and Livingston Group, KJ=Colorado Group, Kootenai Formation and Ellis Group, Pal=Paleozoic section, p€b=Belt Supergroup. From Garrett,1972 Fig.3.

Bridger canyon a doubly plunging syncline along Brackett Creek is visible on aerial photographs (Fig. 5). These photos also suggest several faults exist south and parallel to Battle Ridge, omitting beds on the north limb of the Brackett Creek syncline, while repeating strata south of Nixon Peak (Fig. 5). East of R7E along Brackett Creek structural dips vary between 10 and 20 degrees to the west. In the southern portion of the study area several enechelon folds have been interpreted to be surface wrench features resulting from left-lateral movement along the Nye-Bowler Lineament (Wilson, 1936).

Along the Shields River some Fort Union sediments were apparently deposited at sea level. These deposits are now 1400 meters above sea level. Although sea level during the Paleocene was higher than presently, the majority of the 1400 meter difference is probably attributable to regional uplifting of the entire basin after Fort Union deposition.

Economic Resources

Two small occurrences of copper, lead, silver and gold are associated with the Crazy Mountains intrusives (Bentley and Mowat, 1967). Numerous optical calcite veins occur in Fort Union strata south of the Crazy Mountains. These fracture fillings may have been formed by low temperature hot springs associated with magmatic intrusives (Stoll and Armstrong, 1958). Commercial bituminous coal beds of coking quality occur in the Eagle sandstone south of Livingston. These deposits have reserves estimated at 300 million short tons (Roberts, 1972). Many of these coal seams were developed from the 1860's to the 1930's to fuel locomotives and local industry. Presently these deposits are not being mined. Although numerous oil and gas shows have been reported, commercial quantities have not been located in the Crazy Mountains Basin (Hadley, 1972). No uranium occurrences have been discovered within the basin; however, the Fort Union and Livingston Formations were deposited in environments favorable for uranium concentration and may offer potential resources.

CHAPTER III

DESCRIPTION OF OUTCROPS

Conglomerates

Roberts (1963) defined the Fort Union formation as those sediments above the lowest polylithic conglomerate in the western Crazy Mountain Basin. This conspicuous ridge-forming conglomerate is composed of numerous gravel lenses 2 to 20 m thick which pinch and swell laterally and are commonly multistoried. The contact between the basal conglomerate and the underlying coarse trough-crossbedded sandstones of the Livingston Group displays numerous scour and fill structures. Laterally and vertically conglomerate interfingers with coarse sandstone lenses.

The basal conglomerate is best exposed along Battle Ridge. There individual beds are between 0.3 and 3 meters thick and display large planar tabular crossbeds (Fig. 9). Imbricated, grain-supported clasts range from 2 to 20 centimeters in length, are well rounded and moderately well sorted. The matrix between clasts consists of poorly sorted sandstone and localized calcite cement. These well indurated light olive brown (5Y 5/6) sediments weather dark yellowish brown (10YR 4/2) and conspicuously lack fossilized wood and plant debris.

Volcanic rocks of intermediate composition comprise about 90 percent of the clasts within the basal conglomerate. Clasts are predominantly porphyritic dacites, rhyodacites and quartz latites containing phenocrysts of augite, plagioclase (An_{16}-An_{54}), amphibolite and biotite.

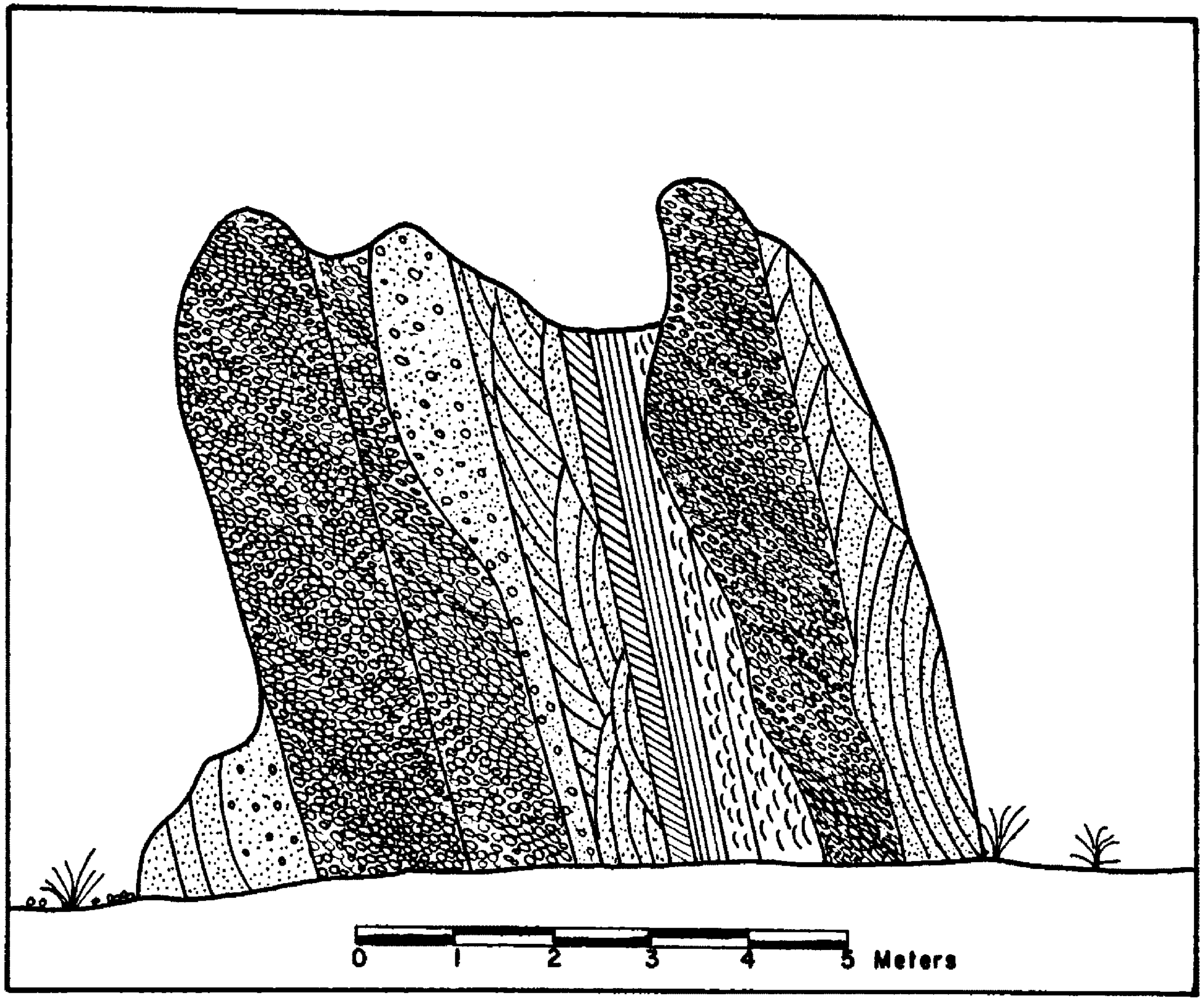

Figure 9 Idealized outcrop of conglomeratic facies exposed at location 3, Appendix Figure A.

Many volcanic clasts have suffered extensive oxidation which altered the groundmasses to hematite, silica and clays. Unaltered groundmasses are typically cryptocrystaline glasses and/or microlitic aggregates of quartz and plagioclase. Well rounded quartz arenite clasts comprise about 9 percent of the basal conglomerate. This stratum also contains clasts of quartz-feldspar amphibole gneisses, amphibole schists, vein quartz, fine-grained, well indurated sandstones, chert and dark finely crystalline fetid limestones. The basal conglomerate, which is thickest along Battle Ridge, thins and fines toward the south and east, suggesting the source area was to the northwest.

At 13 locations I randomly sampled and segregated clasts into compact, elongate and platy categories to investigate the relationship between rock type, clast shape and distance from suspected source areas (Folk, 1974). Although a full spectrum of volcanic clast shapes occur in the northwest portion of the study area, elongate volcanic clasts are generally absent to the south (Fig. 10). This is probably due to breakage of elongate volcanic clasts during prolonged transport. Most quartzite clasts are spherical suggesting derivation from a more distant source or resedimentation from morphologically mature conglomerates. Typically elongate, limestone clasts show no morphological variation because of preferred breakage patterns. The anisotropic weathering of limestone clasts eliminates their use in the morphological study.

A 150 meter thick sequence of interbedded conglomerates and sandstones, similar to the basal unit occurs at the top of the Fort Union on Nixon

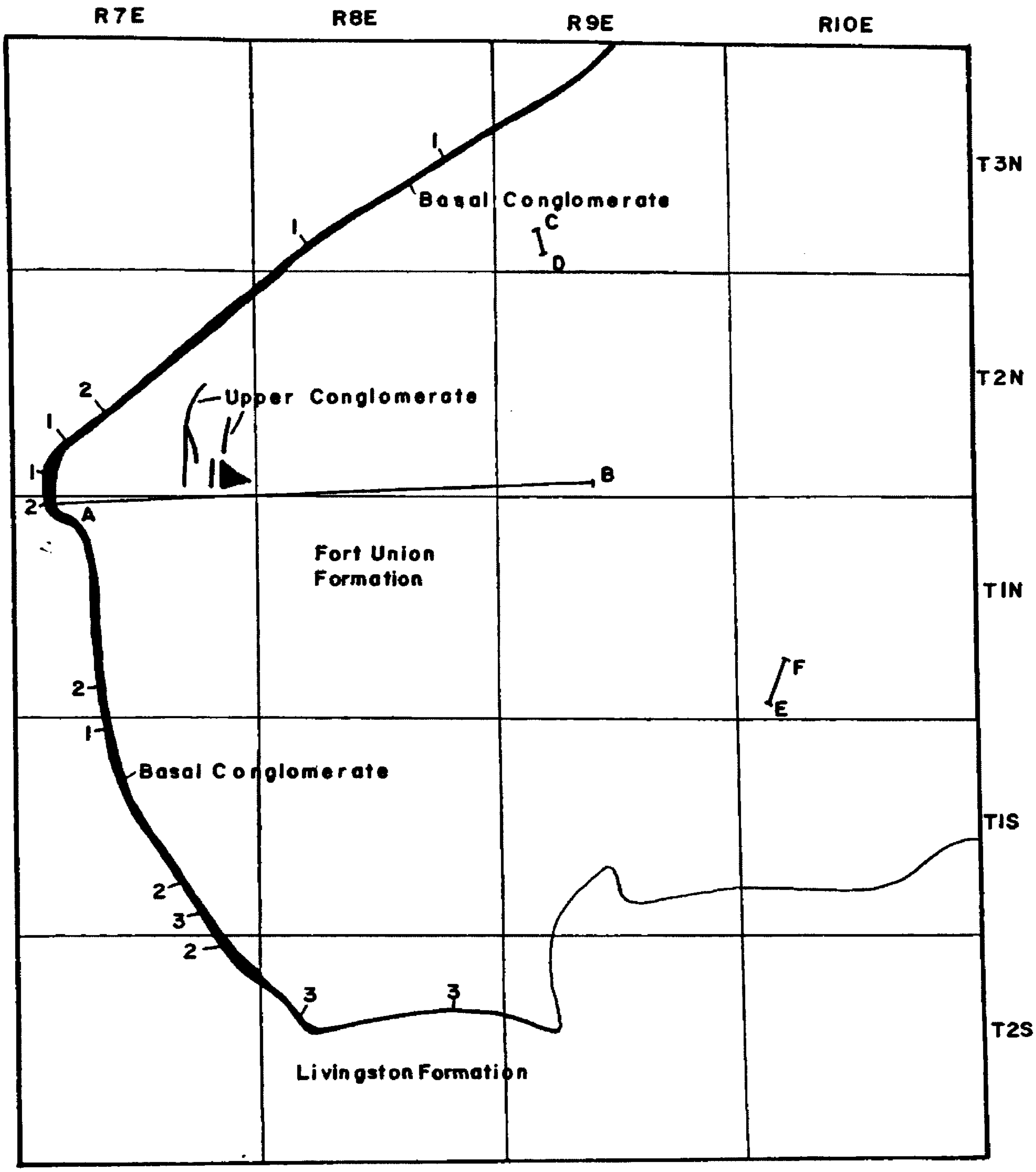

Figure 10 Distribution of conglomeratic facies in the Fort Union Formation.

Key to clast shape data:
1) elongate, platy and compact shapes present
2) elongate clasts present but rare
3) elongate clasts not present

Peak (Fig. 10). It contains approximately 5 percent limestone clasts, suggesting extensive uplift and erosion of a carbonate highland during upper Fort Union deposition.

The conglomerates within the Fort Union were deposited by fluvial processes based on: 1) similarity of sedimentary structures to recent fluvial deposits, 2) intimate association with sandstone displaying fluvial features, 3) angularity of interstitial sand grains, 4) lack of marine fauna. Studies on recent gravels in the Nueces River, Texas (Gustavson, 1978) and Irving Creek, Ontario (Marilini, 1977) describe many features characteristic of Fort Union conglomerates (Table 2). The low sinuosity, moderately high gradient Nueces River deposits gravels on transverse and point bars during periods of high discharge. Following the period of peak flow poorly sorted sand and mud is deposited from suspension on adjacent flood plains. Fort Union conglomerates lack the silt and clay fraction which comprises a significant portion of Nueces River bars. Sand and clay is also absent from the braided Irving Creek gravels (Marilini, 1977). The Fort Union conglomerates were deposited by high gradient braided or slightly sinuous meandering streams during periods of high discharge. Gravel, transported by strong tractive currents was deposited on the accreation faces of channel and point bars under lower flow regime conditions. After peak flow conditions, poorly sorted sands were trapped between framework elements. The essential depositional features preserved within suspected point and channel bars were unaffected by periods of low flow. Deposition of trough cross-bedded

Table 2. Comparison of Nueces River and Irving Creek Gravel Bars with Fort Union Conglomerates

	Nueces River	Irving Creek	Fort Union
Channel stability	moderate	stable	?
Channel cross section	broad shallow, symmetrical to asymmetrical	confined, symmetrical to asymmetrical	Prob. broad to shallow
sinuosity	very low	extremely low	low
gradient	moderately high	high	high
sand and gravel facies geometry	multilateral high gravel/sand	multilateral, sands absent	multilatural, and multistoried, high gravel/sand
vertical sequence of sedimentary structures	c) moderately sorted, horicontally bedded, graded or non-graded, clast supported b) gravel with minor matrix of sand and silt interbedded with thick layers of homogenous poorly sorted sandy mud a) large planar cross-stratification, graded or non-graded horizontally bedded open work of imbricated gravel	none point, transverse and longitudinal gravel bars moderately sorted, clast supported, open framework of horizontally bedded and large planar tabular cross beds	c) moderately sorted horizontally bedded nongraded, clast supported b) poorly sorted sand lenses, horizontally and trough cross bedded. a) large planar tabular cross beds closed work, imbricated gravels
grain size trend	no trend	no trend	no trend

compiled from Marlini, 1977 and Gustavson, 1978.

sands between gravel bars and in bar channels occurred during low flow and decreased sediment supply periods. Episodic channel shifting under peak flow conditions allowed the migration of a continuous gravel sheet throughout the western margin of the Crazy Mountains Basin.

Sandstones

The Fort Union formation contains three distinct sandstone assemblages which I have informally named on the basis of type localities. The typical Area Creek-type sandstone is lensoidal, coarse to medium grained and contains numerous large and small trough crossbeds (Fig. 11). Lenses 10 to 100 meters thick extend laterally from 0.2 to 4 kilometers. On a mega scale the Area Creek section is composed of many sandstone lenses imbedded in a matrix of fine horizontally laminated silt-stone and mudstone. The lenses hold up small discontinuous hogbacks surrounded by grass and sage covered mudstone slopes. Within each lens the scale of sedimentary structures and grain size decreases upwards with the base marked by a choatic potpourri of partially preserved trough crossbeds. Trough crossbeds range from 0.5 to 2 meters thick and contain abundant pebbles, poorly sorted sand, clay rip-up clasts and plant fragments. Tabular, planar crossbeds 20 cm thick, capped by a gravel veneer are locally present. This mozaic of sedimentary structures extends vertically and laterally throughout most of the sandstone lens. Troughs become smaller near the top of a lens and plane horizontally laminated medium-fine-grained sand layers are commonly present. Small

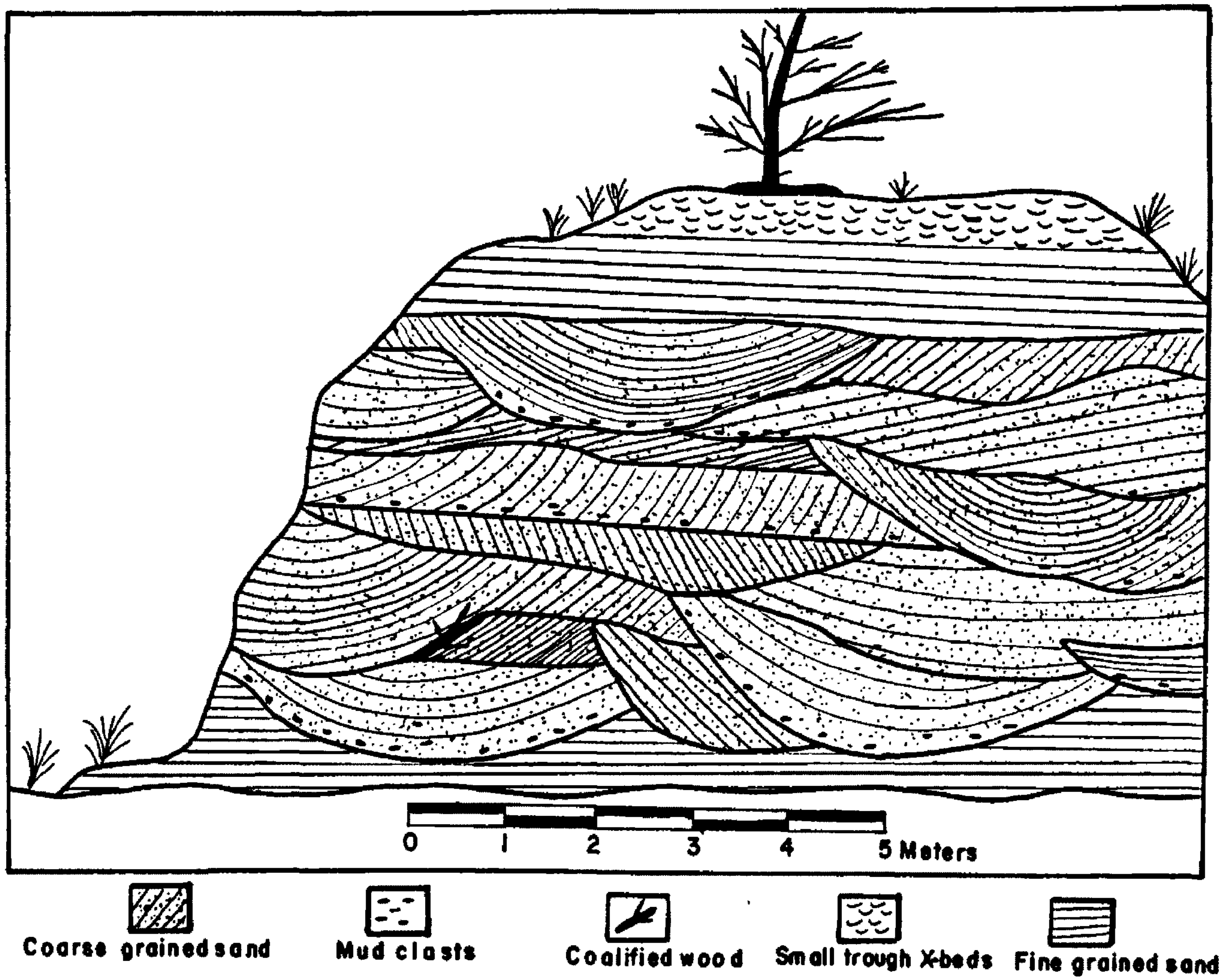

Figure 11 Idealized outcrop of Area Creek-type sandstone exposed at location 26, Appendix Figure B

(7 to 15 cm) trough crossbeds dominate the top of the lens. Ripples are seldom present in the poorly sorted, coarse-grained Area Creek sandstones.

The base of a fining upward lens is characterized by a greater concentration of volcanic rock fragments, clay rip-up clasts and organic debris. The top of a lens may be relatively enriched in opaques, quartz and feldspar. The sandstone is generally light olive green (5Y 5/2) representing deposition under reducing conditions.

The Area Creek sandstones have features characteristic of both the coarse and fine-grained meanderbelt systems described by Brown (1973) and McGowen and Garner (1970). Because those systems are idealized end members in a continuum of natural processes one should except variations from the models (Table 3). Area Creek sandstones were deposited by mixed load, meandering streams, flowing over moderate gradient slopes. Channel units in the Area Creek section show an incomplete point bar sequence; the coarse grained channel lag, scour pool and lower point bar deposits are erosively bounded vertically and laterally by similar channel sequences. During high flow periods the channel base is scoured and infilled by poorly sorted sediments, forming prominent trough cross-bedding. The migration and preservation of small transverse bars produces the small tabular crossbeds of the lower point bar (McGowen and Garner, 1970). Overbank flow deposits sand and silt on floodplains adjacent to the channel, under upper flow regime conditions (McGowen and Garner, 1970). Small scour troughs are also common to flood plain

Table 3. Comparison of Fine-Grained and Coarse-Grained Meanderbelt Systems with Area Creek Sandstone

	fine grained	coarse grained	Area Creek Sandstone
Channel stability	high	slight	?
Channel cross-sections	narrow, asymmetrical	broad, shallow, asymmetrical or symmetrical	?
Sinuosity	high	low	low
Gradient	low	moderate	moderate
Sand facies geometry	multistory, low sand/mud	multilateral high sand/mud	multilateral moderate sand/mud
Vertical sequence of sedimentary structures	climbing ripples small troughs parallel laminae trough cross stratifications and thin foreset cross stratified large trough-fill cross stratified	parallel laminae & thin foreset cross lamination thick foreset cross-stratification large trough fill cross stratification	parallel laminae small troughs small foreset cross stratification large trough fill stratification
grain-size trend	fining upward	no trend	fining upward

from McGowen & Garner, 1970

deposits. After the flood crest passes, stagnent flood plain waters deposit extensive silt and mud drapes from suspended sediment.

The Brackett Creek sandstone facies exposed in road cuts along Brackett Creek, east of Nixon Peak, is characterized by a regular alternation between moderately well sorted, fine-angular-grained sandstone in tabular beds and evenly bedded organic rich mudstone (Fig. 12). Sandstone beds 20 to 50 cm thick contain horizontal planar and ripple cross bedding, along with occasional climbing ripples. Many of these structures have been contorted by compaction of interbedded muds. Trough fill crossbeds 10 to 20 m wide, 1 to 2.5 m thick and symmetrical in cross section commonly scour into the evenly bedded sand and mud layers. Typically these troughs contain poorly sorted sand grains, abundant mud chips, plant debris and small, low-angle, planar tabular and trough crossbeds. Several abandoned mud filled scour channels are associated with scour troughs.

The specific depositional environment responsible for these deposits is uncertain. The regular alteration between thin tabular sand and mud layers suggests a marginal marine depositional environment. Reineck and Singh (1973) describe similar deposits in the Transition Zone of the Cretaceous Mesa Verde Group. The Transition Zone underlies coastal beach and barrier bar sands and overlies shelf mud deposits (Fig. 13). Mud is continuously deposited from suspension below wave base. Periodic storms wash coastal sands seaward forming thin ripple bedded sheet sands. The depth to the top of the transition zone varies from 2 to 20 meters,

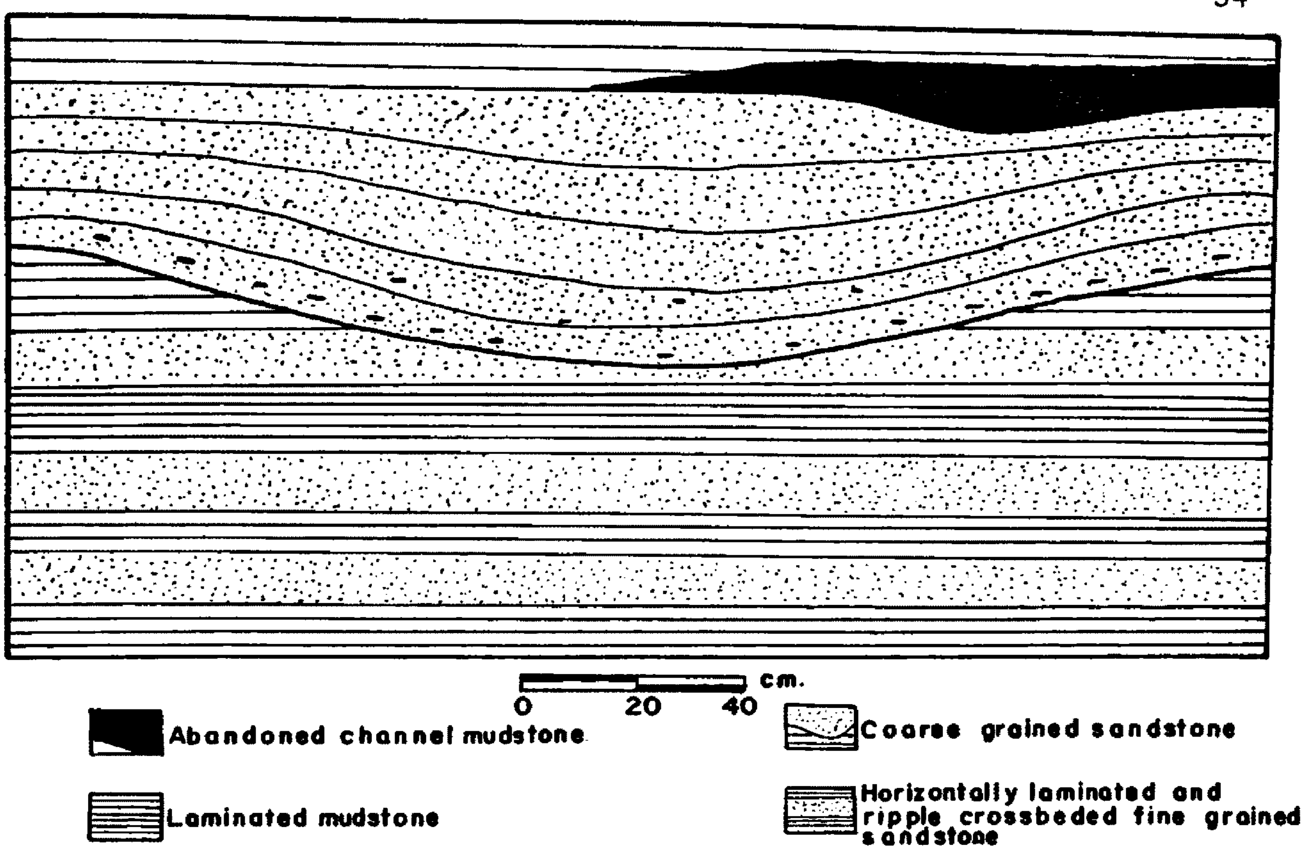

Figure 12 Brackett Creek type sandstone, location 13, Appendix Figure A.

Table 4 Characteristics of Brackett Creek type sandstone

	Evenly bedded sandstone	Scour trough sandstone
grain size	fine grained sand and silt layers interbedded with silty mud layers	medium to fine grained sand with clay rip-up clasts
sorting	moderately well sorted	moderately sorted
bedding	plane beds 20 to 50 cm thick	trough crossbeds 50 to 90 cm thick
sedimentary structures	ripple cross bedding, horizontal laminations load structures contorted laminations rare climbing ripples	small scale troughs plane beds flute casts load structures abandoned channels
sand geometry	tabular sheets	isolated lenses

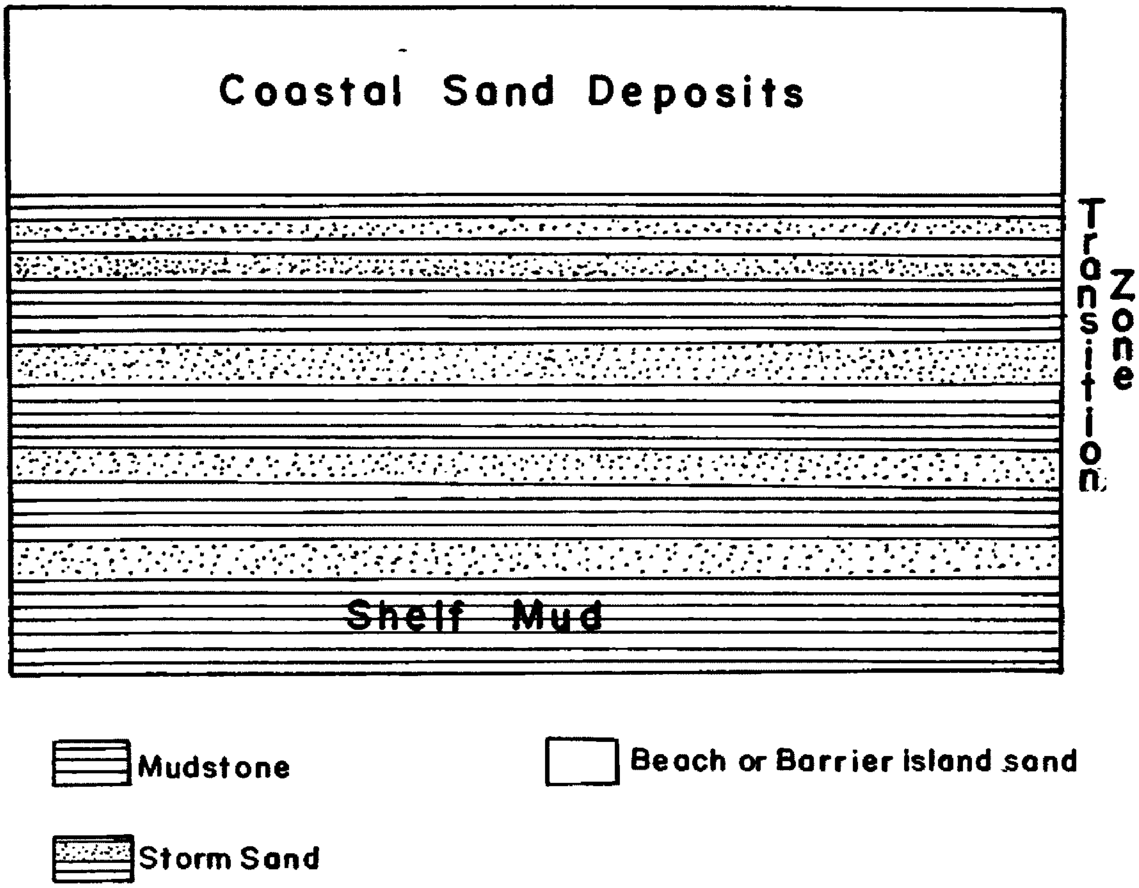

Figure 13 Transition zone sands and muds. Modified from Reineck and Singh (1973), Fig. 504.

while the base of this environment ranges from 8 to 30 meters (Reineck and Singh, 1973). Streams entering this marginal marine setting may have generated strong submarine currents, scouring evenly laminated sands and muds, forming the large trough crossbedded sandstone.

The Brackett Creek facies also contains features similar to recent delta topset deposits. In this interpretation the tabular sand sheets are levee and crevasse splay deposits formed under flood conditions. As flood waters overtop stream banks, the velocity is reduced, causing deposition of suspended sediment, near the channel as levees (Fig. 14). Later floods may breach levees, diverting water and sediment into adjacent flood basins. Sand is rapidly deposited in broad sheet-like tongues, several to 100's of meters wide, displaying ripple crossbedding, climbing ripple lamination and horizontal bedding (Reineck and Singh, 1973). As the floodcrest passes, clays slowly settle from stagnent flood plain waters forming extensive, evenly laminated, tabular mud layers. Periodically, distributary channels migrate laterally, scouring into flood basin deposits producing large trough, channel-fill sandstones. Stratigraphic relationships (Chapter IV) favor the delta topset origin for the Brackett Creek facies.

Excellent exposures of the Chadborn-type sandstone may be seen near Chadborn and Clyde Park, along the Shields River. The base of the sequence at Chadborn consists of a 9m thick massive, moderately well sorted, fine-grained sandstone (Fig. 15). Within this grayish-green (5G 5/2) sandstone several 20cm thick planar tabular crossbeds occur;

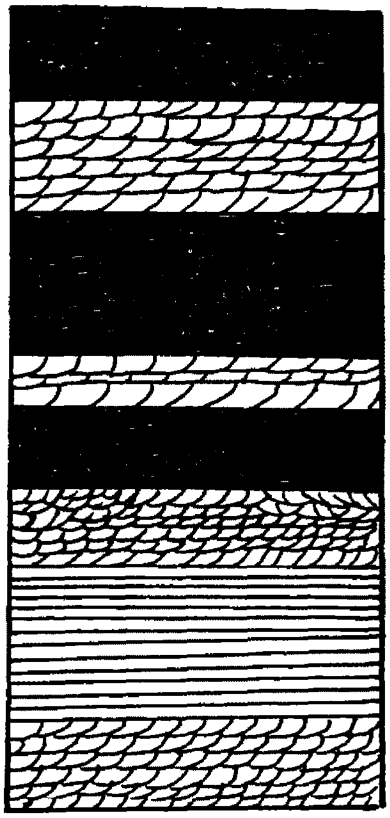

Figure 14 Sedimentary structures in the natural levees of the Gomti River, India. From Reineck and Singh (1973), Fig. 366

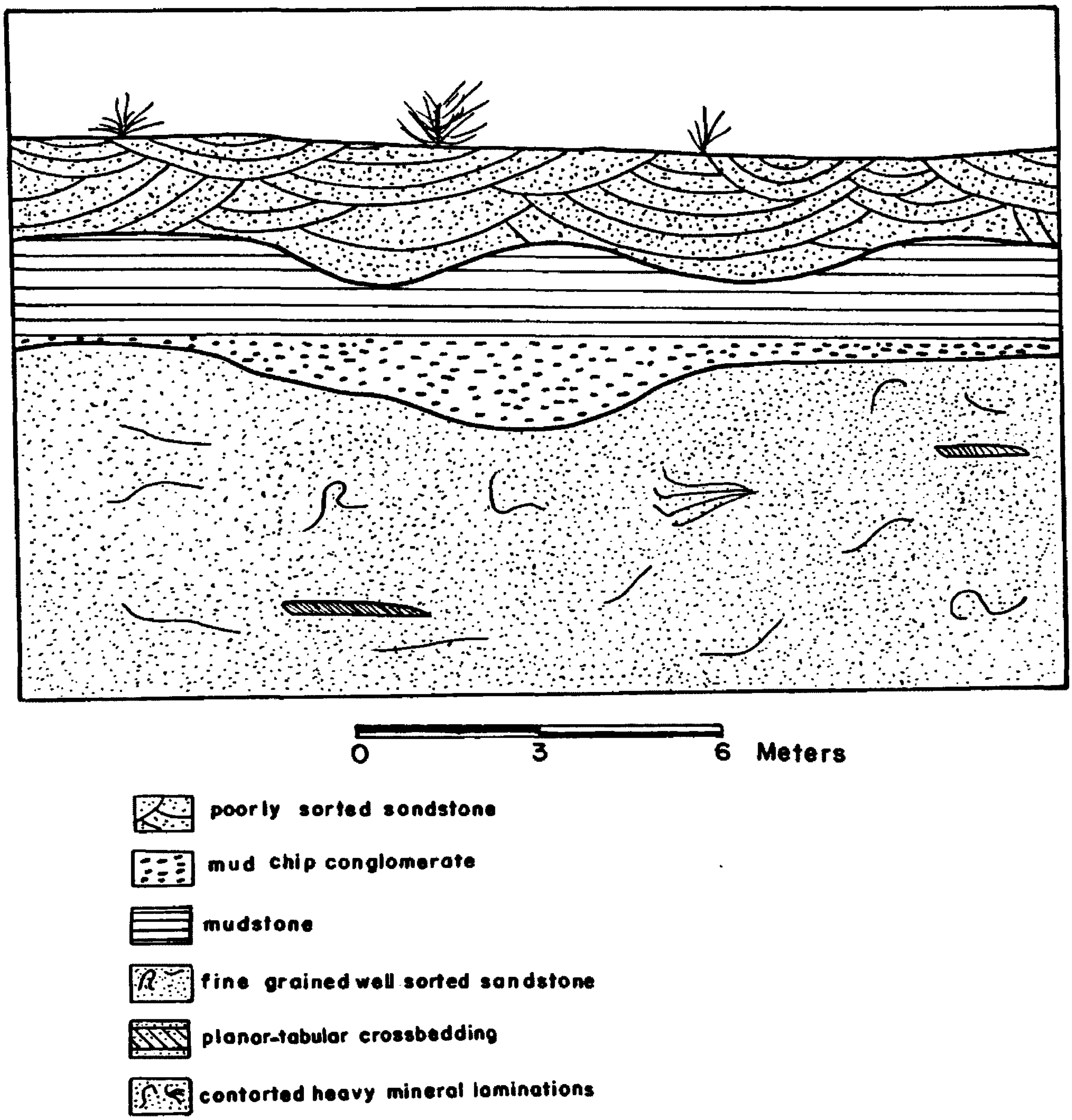

Figure 15 Chadborn-type sandstone, exposed at location 22, appendix Figure A.

however most sedimentary structures were obliterated by deformation during compaction. Exposures near Clyde Park display horizontal laminations when not disrupted. Several troughs are scoured approximately 2m into the top of the massive sandstone. Some troughs are filled with mud chips and organic debris, while others contain small trough-crossbedded, poorly-sorted sandstone.

These sedimentary features are characteristic of bar finger sands and distributary channel fills (Brown, 1973; Fisk, 1961). Bar finger sands are deposited in shallow water, seaward of a distributary channel, above prodelta foreset muds (Fig. 16). Low sinuosity, symmetrically filled distributary channels commonly scour into the underlying bar finger sands. These channels deposit trough and ripple crossbedded sands while active and when abandoned infill with mud and plant debris.

Paleocurrents

One hundred fifty-four bearing and plunge measurements of trough crossbed axes were collected within the study area. Trough axes conform within a few degrees to the actual channel trend (McGowen and Garner, 1970) and should be the most reliable indicator of paleocurrent directions. Crossbedding measurements were corrected for tectonic tilt with the aid of a stereonet and the resulting vectors compiled on rose diagrams (Figures 17 and 18). Although there is some scatter, the dominant direction of transport, and therefore regional slope, was toward the southeast. Over 80 percent of the measurements were collected from Area Creek type sandstones and the lack of appreciable scatter

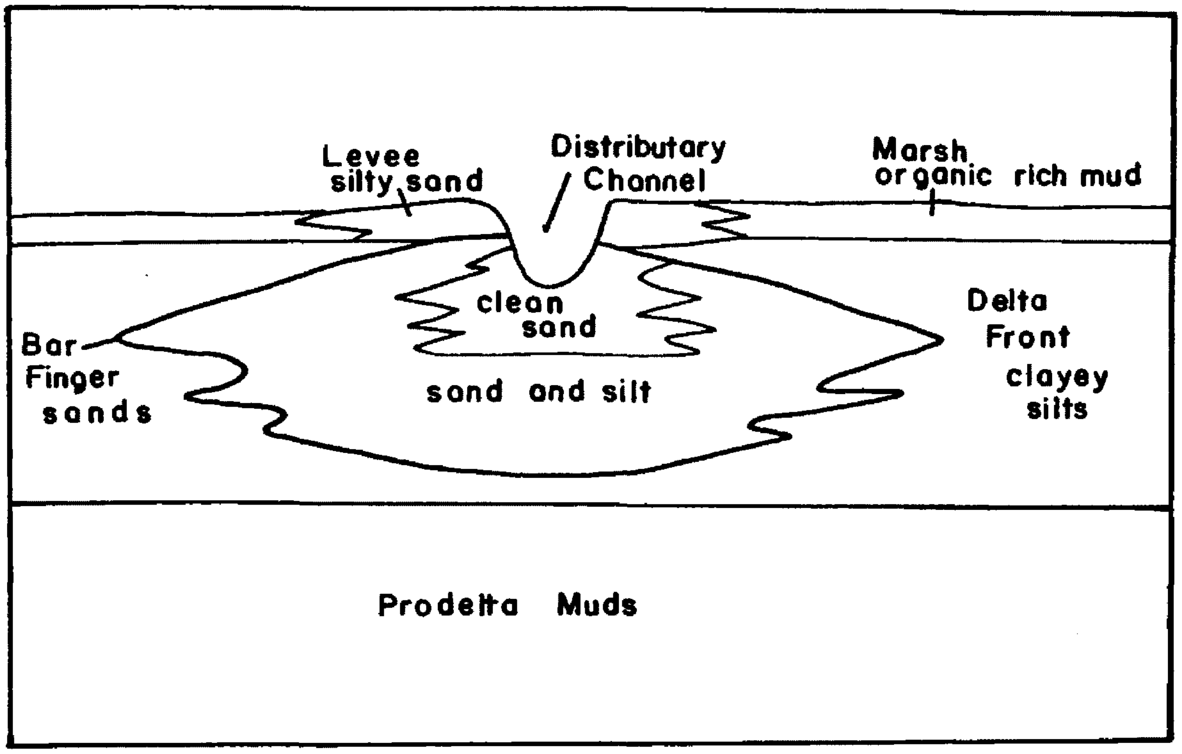

Figure 16 Bar Finger Sands and Associated Environments modified from Fisk(1961)

Table 5 Characteristics of Bar Finger Sands

1) Fine sands and silts
2) Absence of fauna
3) Plant debris
4) Thin laminae of sand and silt
5) Sedimentary structures:
   a) clean, well sorted, laminated sands
   b) thin, planar-tabular crossbeds
   c) small trough crossbeds common throughout
   d) contorted layers formed by settling of bar into Prodelta muds

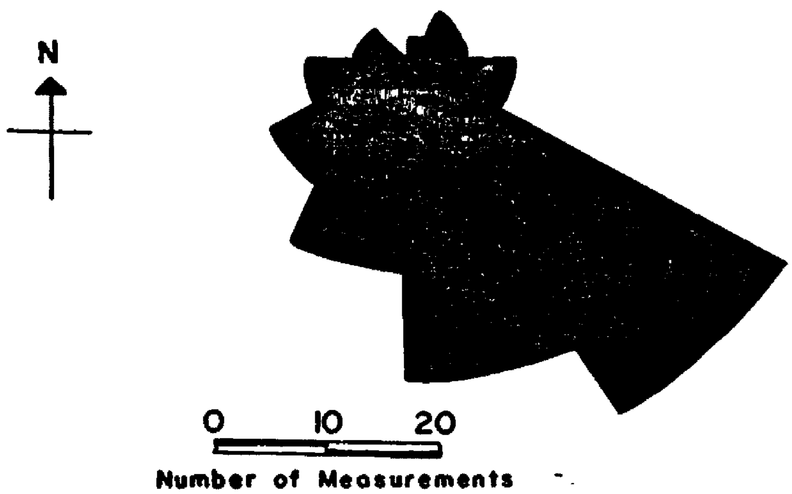

Figure 17 Composite Paleocurrent Rose for the Fort Union Fm.

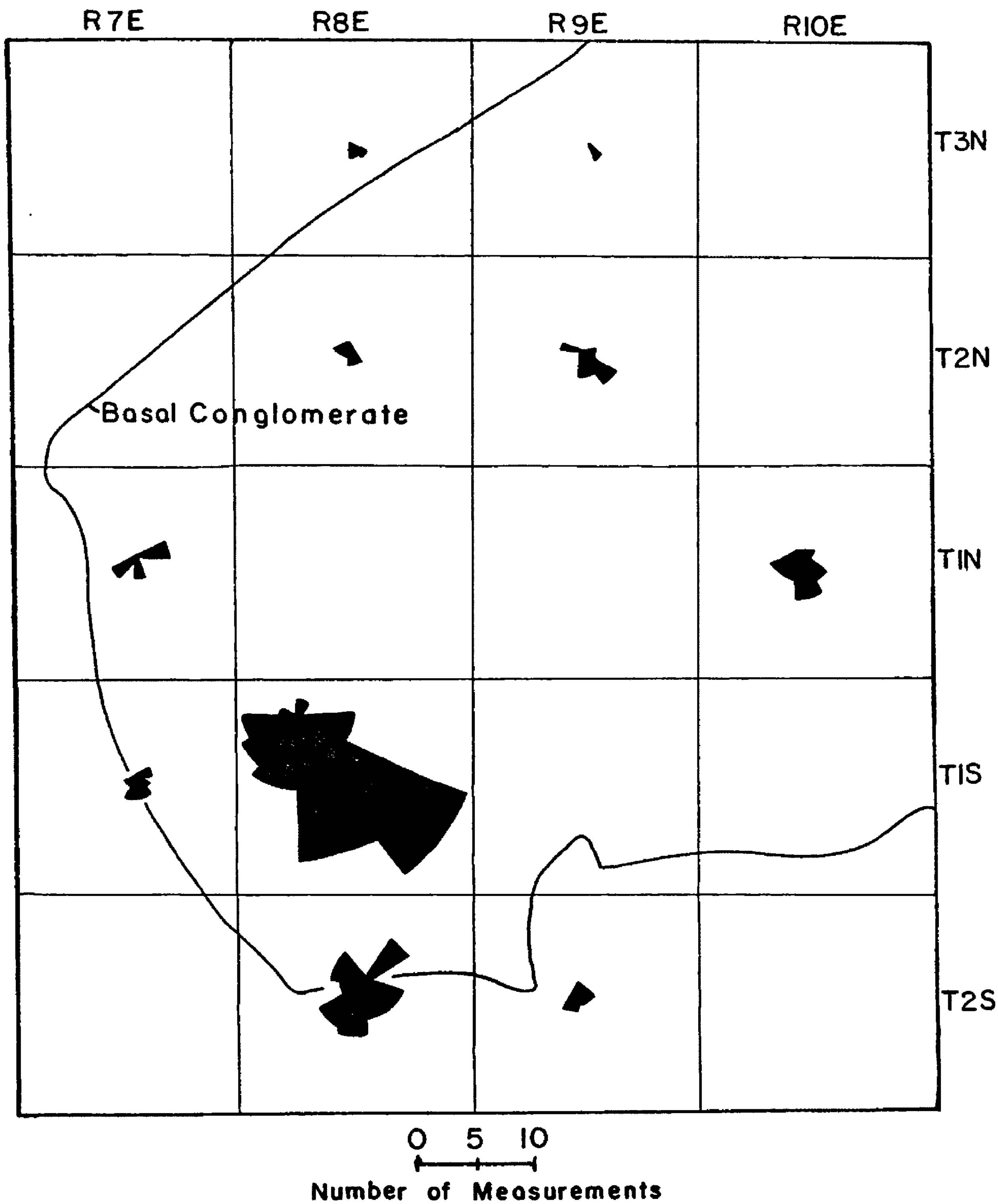

Figure 18 Paleocurrent directions in the Fort Union Formation by township.

suggests deposition by low sinuosity streams (McGowen and Garner, 1970). Anomalous paleocurrent directions in T2S, R8E (Fig. 18) suggest localized deposition by high sinuosity streams. The northeast paleocurrent trends in this rose may represent troughs formed by back flow along channel margins.

Petrology

Sandstones of the Fort Union formation are extremely immature and most classify as lithic arenites (Folk, 1974) because of the preponderance of volcanic detritus. Petrographic descriptions and sample locations are listed in Appendix 1. The major detrital constituents are volcanic rock fragments and devitrified glass (2 to 75%), quartz (7 to 60%), plagioclase (0 to 6%), and augite (0 to 46%). Minor detrital components include sedimentary and metamorphic composite quartz, orthoclase, carbonate rock fragments, biotite, chlorite, muscovite, magnetite, illmenite, chalcedony, tourmaline, amphibole and leucoxene.

Most quartz grains are clear, angular and embayed, with straight extinction, suggesting a volcanic source. A smaller population of quartz grains is well rounded, with straight to undulose extinction and rare reworked overgrowths suggesting derivation from sedimentary rocks. Quartz angularity decreases slightly toward the east although some Chadborn-type sandstones contain significant amounts of angular quartz (Fig. 19). Quartz grains from fluvial conglomerates and Area Creek type sandstones are fairly angular and show only minor rounding with increased transport distances. Quartz content clearly increases up-section

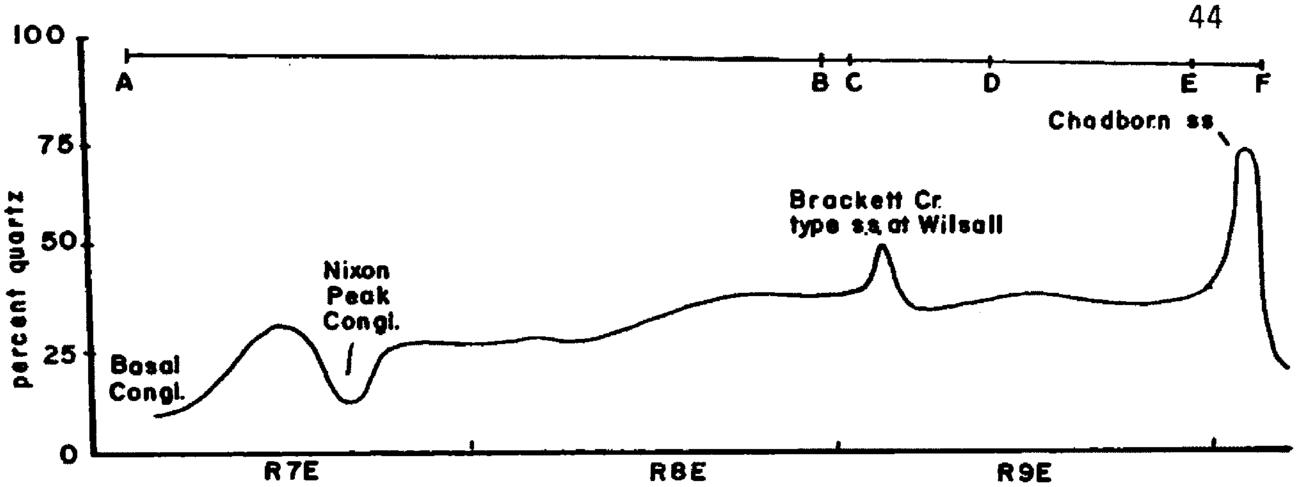

Figure 19 Variation in quartz content along Brackett Creek. Line of section A-F shown on Figure 10.

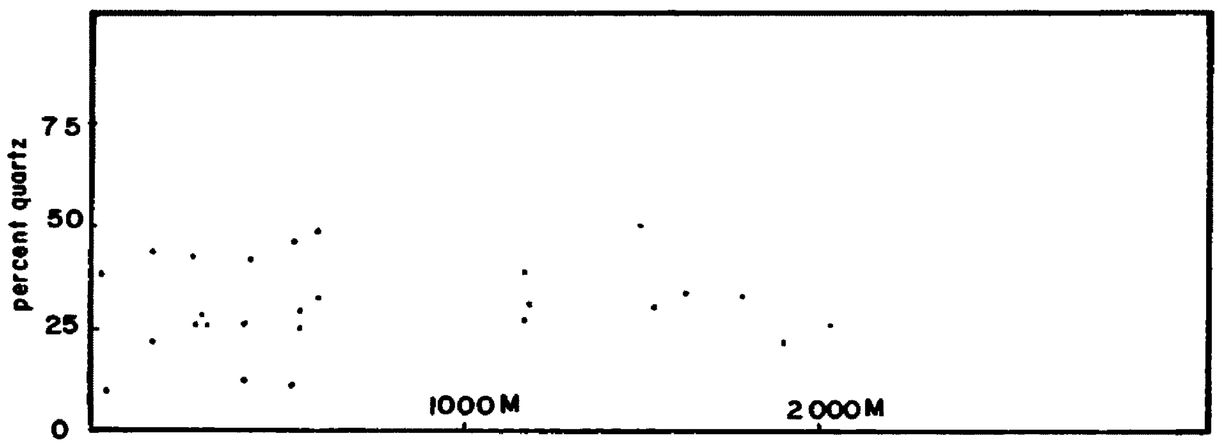

Figure 20 Variation in quartz content along Area Creek section. Location see Figure 5.

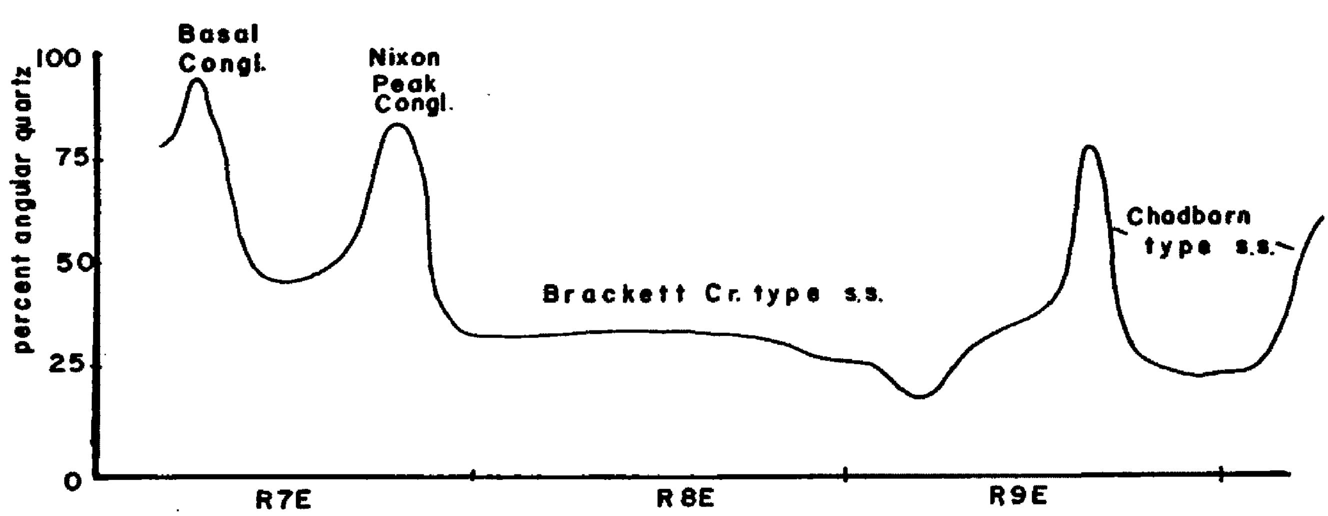

Figure 21 Variation in quartz angularity along Brackett Creek. Line of section same as Figure 19.

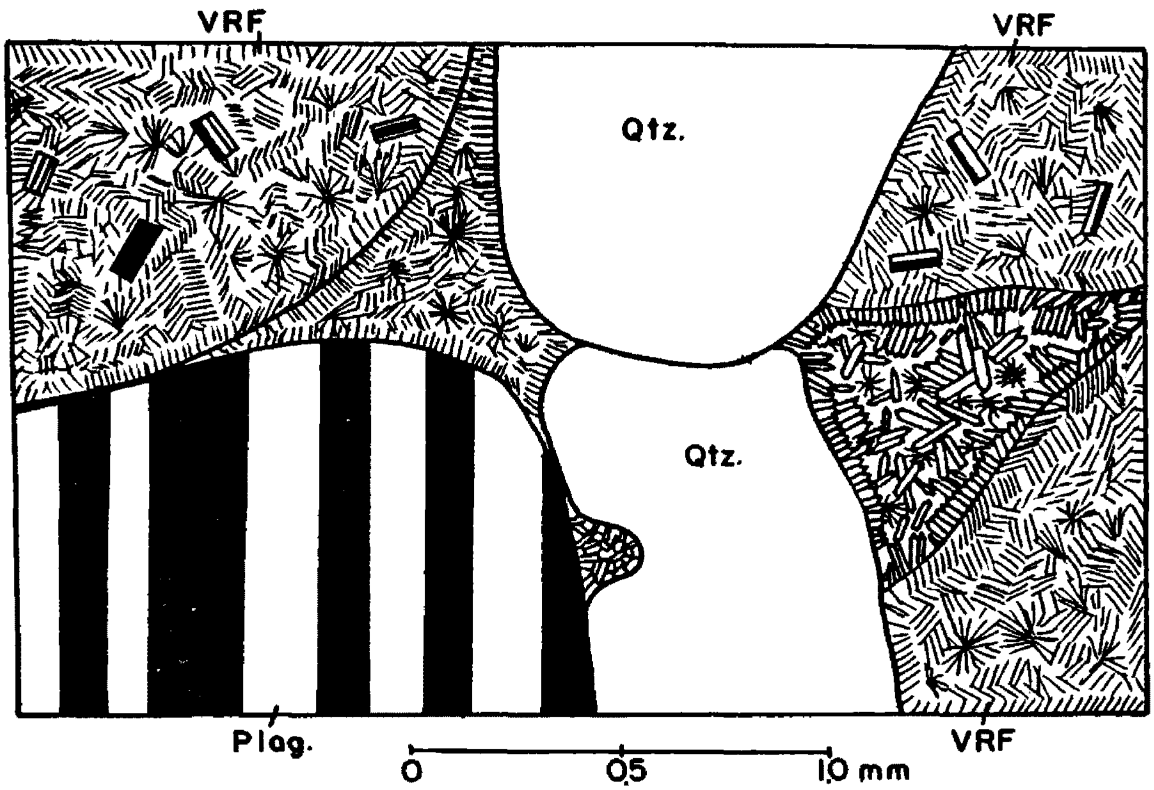

Figure 22 Thin section of typical Area Creek sandstone. Euhedral quartz crystals growing in pore space on right. Fibrous clay minerals growing in pore spaces and altered volcanic rock fragments. VRF denotes volcanic rock fragment.

(Fig. 20) and eastward (Fig. 21), at the expense of volcanic detritus. Coarse conglomeratic sandstones (basal conglomerate, Nixon Peak conglomerate, basal and upper Area Creek lenses) have less quartz than the finer-grained middle Area Creek section, Brackett Creek and Chadborn type-sandstones (Figs. 20 and 21). This is probably the result of extensive reworking of sediments in fine-grained environments.

Plagioclase and especially orthoclase are often altered to clay minerals. Many plagioclase grains are euhedral, zoned and larger than quartz grains: textural inversion (Folk, 1974). This suggests a feldspar source close or closer than that of quartz. Plagioclase compositions vary between An_{12}(oligoclase) and An_{54} (labradorite) with andesine being predominant.

Augite, derived from a volcanic source is particularly abundant in sandstones associated with conglomerates and coarse Area Creek lenses. The occurrence of large quantities of this unstable mineral in coarse clastic horizons implies rapid mechanical disaggregation, with little chemical alteration of source materials during periods of profuse sediment production.

The most interesting and perplexing aspect of Fort Union petrology is the diagenetic alteration of unstable volcanic detritus which created a petrographic nightmare. Unaltered volcanic fragments are seldom observed. Most grains have altered to chlorite, smectite, serpentine, chert and/or clinoptilolite, producing the olive green coloration characteristic of Fort Union sandstones. Frequently individual grain boundaries are indistinguishable because of the extensive diagenetic alteration. Alteration of volcanic detritus released abundant silica which precipitated as syntaxial overgrowths on quartz grains. Additional silica precipitated interstitially as opal which commonly altered to chalcedony and chert. In most thin sections silica appears to be the first formed cement. Calcite cement apparently precipitated after silica, as expitaxial overgrowths and interstitial impregnations. Calcite cements are extensive in Chadborn type sandstones, the Nixon Peak sandstones and the upper Area Creek sandstones.

Clay Mineralogy

Clay minerals within the Fort Union formation occur as detrital particles (in shales) and anthigenic components of sandstones and conglomerates. Most fluvial channel sandstones have little if any detrital clays when deposited (Wilson and Pittman, 1977). Therefore, the clay assemblage within Fort Union sandstones probably represents the alteration of framework grains during diagenesis.

Thin sections of Fort Union sandstones reveal authigenic clays as pore linings, pore fillings and replacements of volcanic glass, volcanic rock fragments and feldspars. Although visible in thin section, the precise identification of clay minerals was made by X-ray diffraction analysis. Sixteen samples of shale, sandstone and conglomerate matrix were analysed (Table 6, Figure 23). From the less than two micron size fraction of these sediments, oriented, glycolated and random slides

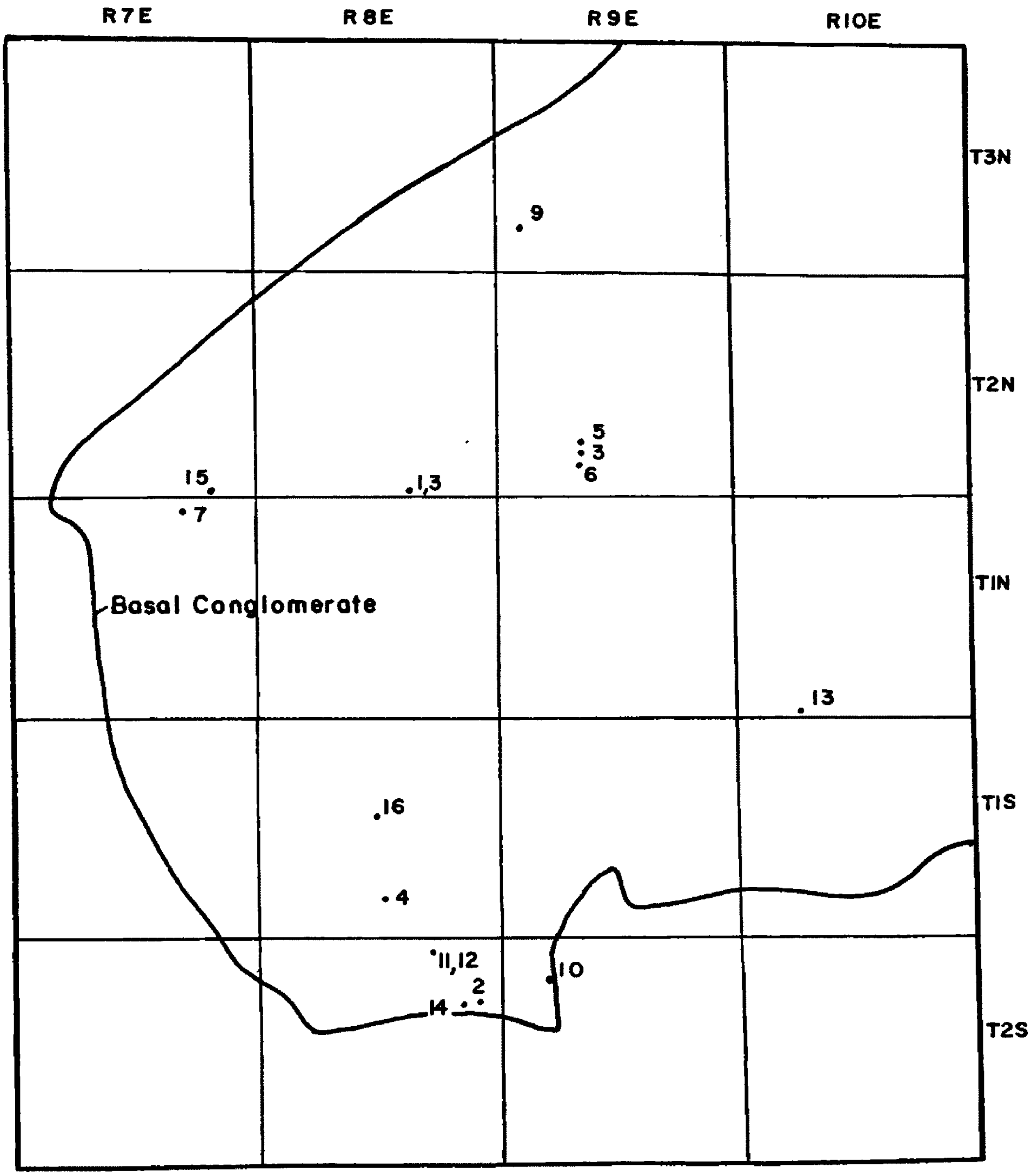

Figure 23 Location map of clay samples.

Table 6. Clay Mineralogy of Fort Union Conglomerates, Sandstones and Shales

Sample Location	Rock type	Mineralogy of less than 2 micron size fraction	Position in section from base
1	shale	serpentine	M
2	shale	serpentine, mixed layer chlorite-smectite, minor illite	183m
3	shale	serpentine, mixed layer chlorite-smectite, minor illite	M
4	shale	mixed layer chlorite-smectite, clinoptilolite	183m
5	shale	serpentine, illite, mixed layer chlorite-smectite	M
6	shale	serpentine, illite, chlorite-smectite	M
7	shale	serpentine, smectite	M
8	shale	serpentine, smectite	M
9	shale	serpentine, mixed layer smectite chlorite	60m
10	shale	illite, smectite	580m
11	sandstone "oxidized"	serpentine, mixed layer smectite-chlorite	520m
12	sandstone-silica & calcite cemented	serpentine, mixed layer smectite-chlorite clinoptilolite	520m
13	fine grained sandstone	serpentine, mixed layer smectite-chlorite	M
14	sandstone-calcareous	serpentine, clinoptilolite, mixed layer smectite-chlorite, minor illite	150m
15	Matrix of conglomerate	serpentine, clinoptilolite, mixed layer smectite-chlorite	3040m
16	sandstone	clinoptilolite, mixed-layer smectite-chlorite	2200m

M indicates middle Fort Union, exact stratigraphic location unknown were prepared and X-rayed. Some samples were acidified to differentiate between kaolinite and serpentine while others received potassium and magnesium treatments to enhance the vermiculitic and chloritic properties of mixed layer clays.

Most samples contained serpentine (Mg, Fe, Si_4, O_{10} $(OH)_8$, 7A peak, acid soluble), illite (KAl_2 $(OH)_2$ Al Si_3 $(OOH)_{10}$, broad 10A peak), smectite ($NaAl_5$ Si_7 O_{20} $(OH)_4$, 12A peak expandable to 17A) and a mixed layer chlorite-smectite with varying degrees of expansibility (Table 6). Additionally, 5 samples contained the zeolite clinoptilolite (K, Na, Ca, Al Si_4 O_{10} $\cdot$ $5H_2O$, 8.9A peak). No relationship between lithology, stratigraphic position and authigenic assemblage was observed.

Mankin (1970) reports that both illite and smectite can form in a semi-arid climate from the alteration of volcanic ash. Clinoptilolite forms by the dissolution of volcanic glass under alkaline (ph7.5-8.1) conditions (Hay, 1966). Since the authigenic mineralogy should reflect the chemistry of the postdeposition environment I suggest that diagenetic groundwaters within the Fort Union contained copious quantities of K, Na, Ca, Mg, Fe and Si ions. This important point will be discussed in Chapter V.

Mudstone

Fine-grained sediments are rarely exposed in the study area. Mudstones and siltstones are absent from the coarse conglomeratic facies but comprise about half of the total sediment in the Area Creek facies. Typically, mudstones are grayish olive-green (5 6Y 3/2), thinly bedded, organic rich and contain numerous angular silt-sized grains. Mineralogically, detrital mudstones contain a clay suite similar to the authigenic assemblage of adjacent channel sandstones (Table 6). Mudstones were deposited on flood plains in the Area Creek facies, as abandoned channel fill in the Chadborn facies and possibly as sub-wave base suspension deposits in the Brackett Creek facies.

Limestone

The Area Creek section contains three small micritic limestone lenses. These beds are approximately 40cm thick, a kilometer in lateral extent and pinch out in mudstones. Some micrites display wavy algal laminations containing an abundance of silt-sized detritus. The detrital fraction varies from 10 to 25 percent and consists mainly of quartz. Stratigraphic relationships between mudstones and micritic lenses suggest these to be fresh water lakes on the flood plain environment (Figure 24).

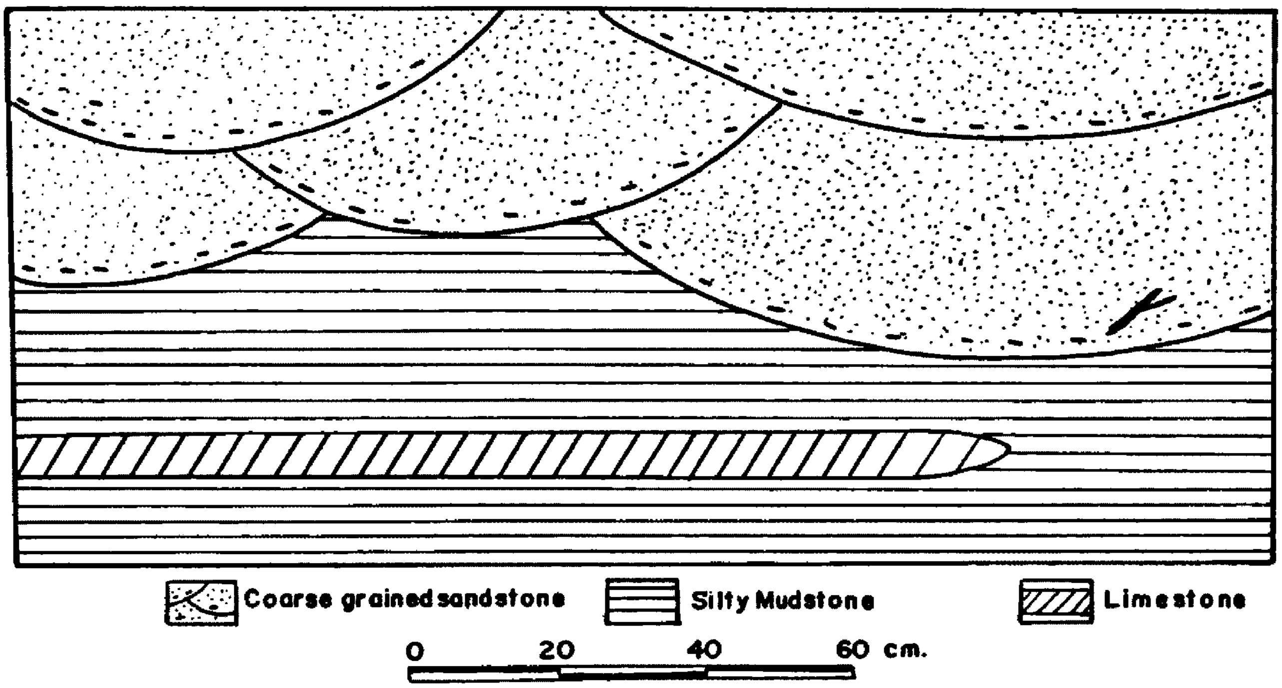

Figure 24 Limestone lens exposed in Perkins Creek. Location 42, Appendix Figure B.

CHAPTER IV

SEDIMENTARY MODEL

Source Area

The preponderance of andesitic volcanic rocks in the Fort Union led Roberts (1963) to the conclusion that the Elkhorn volcanic field was the major source area. However, the basal Fort Union conglomerate fines rapidly from northwest to southeast suggesting a source area closer than the present eastern limit of the Elkhorn field.

A wide assortment of andesitic volcanic rocks are contained in the Maudlow Formation, west of the Bridger Range (Fig. 4). Fragments of blue-green vitric crystal tuff of the Maudlow Formation (member E) have been recognized as clasts within the basal Fort Union conglomerate. Additionally, paleocurrent directions indicate a source area in the vicinity of the Maudlow Formation. The Maudlow volcanics probably correlate with the Elkhorn and Wolf Creek volcanic fields (Skipp and McGrew, 1977), originally forming a huge volcanic pile covering as much as 26,000 square kilometers of Central Montana (Smedes, 1966). The many cubic kilometers of volcaniclastic sediments within the Livingston Group and Fort Union Formation clearly support this interpretation. Most of the volcanic detritus was probably derived from the eastern edge of this pile, of which the Maudlow Formation is only an erosional remnant.

As noted earlier, quartzite clasts exhibit greater morphological maturity than softer volcanic clasts. This morphological inversion may be due to recycling of quartzite clasts from an older conglomerate or derivation from a more distant source area. Descriptions of clasts contained in the nearby LaHood and Kootenai conglomerates bear little resemblance to Fort Union quartzite clasts. Quartzites may have been derived from the Pennsylvanian Quadrant sandstone or the Precambrian basement.

The Precambrian basement is exposed north of the Crazy Mountains Basin in the Little Belt Mountains. However these exposures are surrounded by Beltian sediments which have not been recognized in the basal Fort Union conglomerate. Basement exposures to the south of the basin are not associated with Belt rocks, but there is little paleocurrent evidence suggestive of north or northeast transport of Fort Union sediments. Furthermore the basal Fort Union conglomerate thins and fines along the southern margin of the basin. Precambrian basement exposures in the Bridger Range are too far south to provide detritus to the extensive Battle Ridge conglomerates. Perhaps during Fort Union deposition the crystalline basement was exposed west of the present Bridger Range and in the later Tertiary a portion of this highland was downdropped forming the Three Forks basin (Fig. 25). Paleozoic limestones and sandstones may have been eroded from exposures near Mandlow or from the Bridger Range.

Facies Reconstruction

Sims (1967) interpreted the Livingston Group as a floodplain-delta system dispersing sediment northeastward. A flood of coarse-grained detritus, derived from the Elkhorn volcanic pile and freshly exposed basement prograded over the finer-grained Livingston sediments, initiated Fort Union sedimentation. The deposition of the basal Fort Union conglomerate may have been the result of either tectonic uplift or a climatic change. However, the geometry of the basal conglomerate and the paleocurrent directions within the Fort Union suggest that the tectonic slope of the Crazy Mountains basin changed after Livingston deposition. I feel this is indicative of tectonism uplifting new source areas and changing the geometry of the basin.

I interpret the Fort Union Formation as a series of coalescing alluvial fans, deposited east of a mountainous source area, in a tectonically active downwarping basin. On the proximal, high gradient portion of the alluvial apron coarse clastics were transported during flood stage by braided or slightly sinuous streams (Figs. 25 and 26). Gravel was deposited in channel and point bars under lower flow regime conditions. Receding floodwaters deposited trough cross-bedded sands adjacent to gravel bars. High gradients on the proximal portion of the Fort Union fan prohibited the development of fine-grained flood plain deposits.

Further down the fan, the conglomeratic facies interfingers laterally with the Area Creek sandstone facies. Moderately sinuous, mixed load

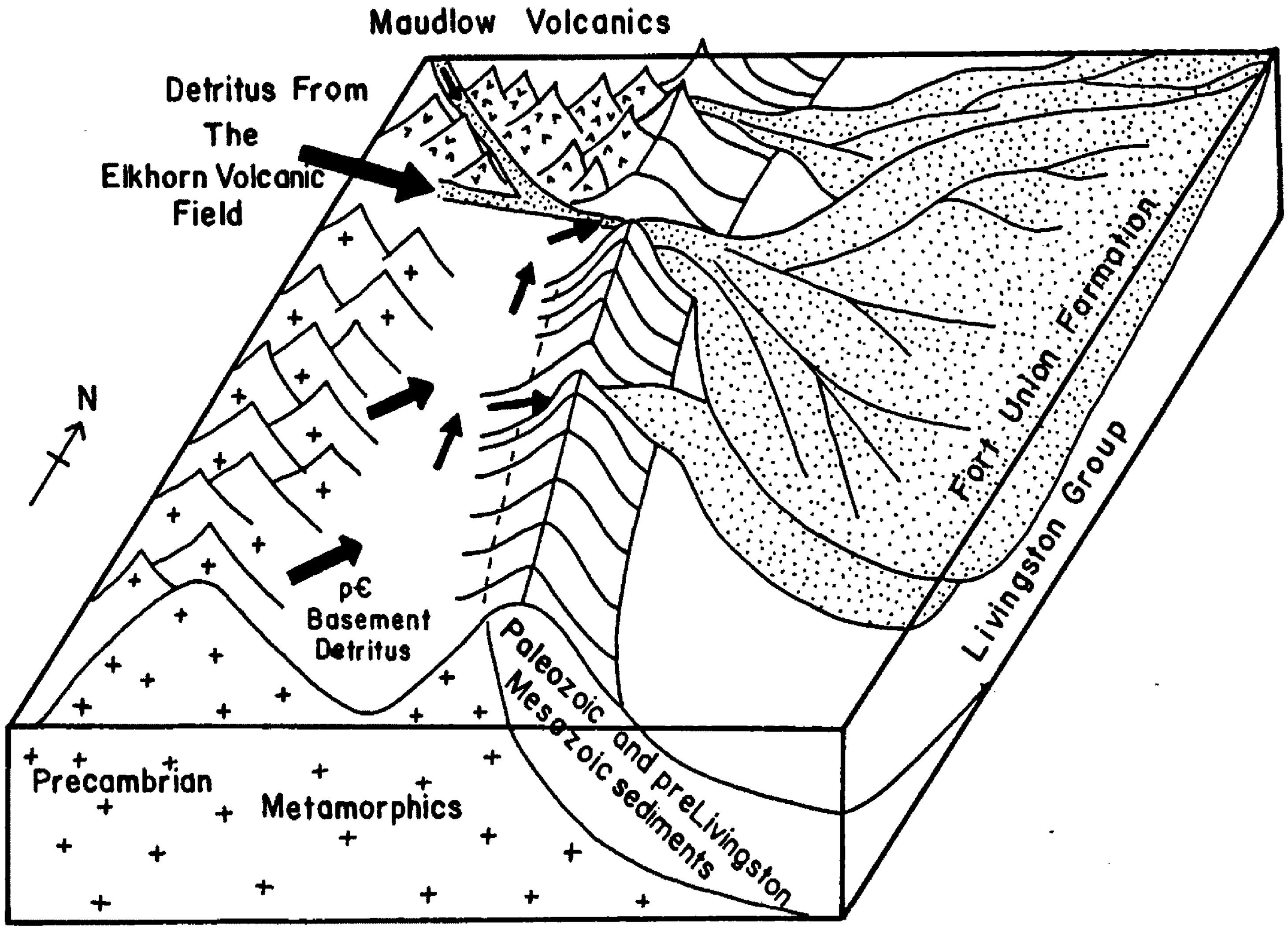

Figure 25 Block diagram of hypothesized paleogeography during Fort Union deposition.

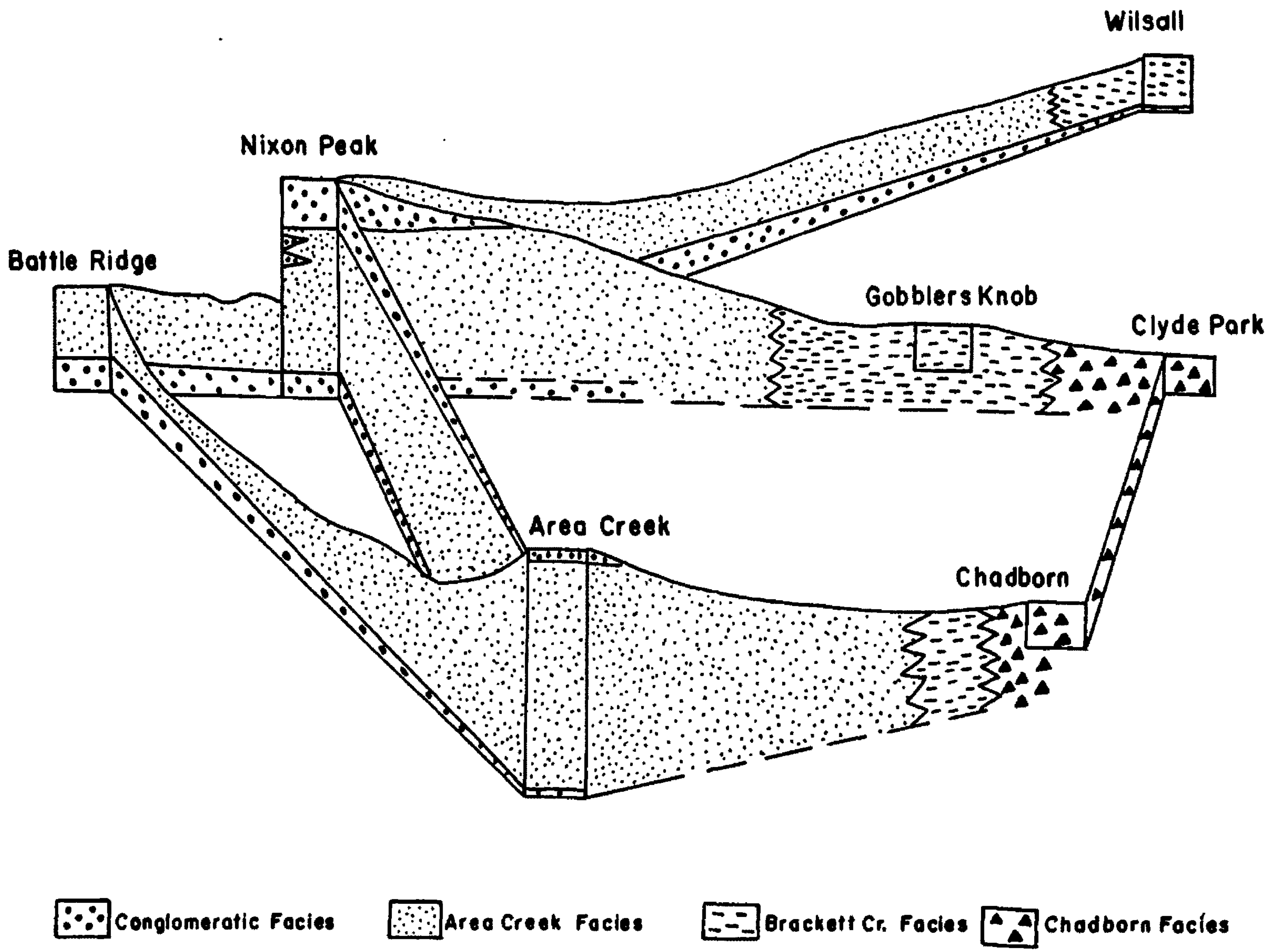

Figure 26 Fence diagram showing facies relationships within the Fort Union Formation. Locations shown in Figure 5.

streams flowing on moderate gradient slopes deposited poorly sorted sands in scour pools and on lower point bars. Periodic flooding scoured into previously deposited sediments creating a choatic array of partially preserved channel deposits. High flow conditions also inundated adjacent flood plains and deposited silts and muds from suspension. Based on paleobotanical evidence, Wolfe (1978) suggests that the climate at this time was mesic to humid and significantly warmer than the present. Moderately high precipitation probably maintained small ephemeral lakes on swampy vegetated flood plains and preserved carbonaceous debris under reducing conditions.

The basal sand lenses of the Area Creek section are large and very coarse-grained. The middle of this section is finer grained and contains extensive overbank deposits. The lower Brackett Creek section is dominated by the conglomeratic facies and represents deposition on the upper reaches of the apron. In the middle of this section the conglomeratic facies is replaced by the Area Creek sand facies (Fig. 26). This basin-wide fining during middle Fort Union deposition may have been caused by several factors operating independently or jointly. If the source area became tectonically quiescent, erosion and sedimentation would develop a graded (or nearly graded) profile from the source area to the distal portion of the fan. Low stream gradients would limit the extensive transportation of gravel. Additionally, chemical weathering would assume a greater role in a moderately low relief source area, increasing the amount of clays supplied to the basin. The absence of conglomerates on the apical portion of the apron during middle Fort Union deposition supports this possibility. An increase in precipitation on a tectonically quiescent low relief source area would also result in finer grained detritus. Additionally if sea level rose, the quilibrium profile of the fluvial environment would be upset. Streams would deposit sands and thick overbank deposits to re-establish equilibrium conditions (McCave, 1969).

The Area Creek facies grades into the Brackett Creek facies at 110°45' along Brackett Creek (Fig. 26). The Brackett Creek facies is interpreted to have formed either in a delta topset or marginal marine environment during the deposition of the middle Fort Union. This rock type is located stratigraphically above the east of the Chadborn bar finger sands. If the Brackett Creek facies is a marginal marine deposit, it represents an extensive transgression inundating most of the Crazy Mountains basin. The transgression would also explain the fining of the middle Fort Union. A coastal sand body would be necessary to supply storm sands to the hypothesized transition zone environment. However, beach or delta facies were not recognized west of the Brackett Creek facies. I therefore suggest the Brackett Creek rock type is a distributary channel, levee, cravasse splay and flood plain deposit on the low gradient distal portion of the Fort Union fan.

The Brackett Creek environment grades into the Chadborn facies along the Shields River (Fig. 26). Low stream gradients on the distal fan allowed only fine sand and mud to be transported. Sand was deposited as channel fill and, where distributaries met marine waters, as bar finger sands. Wave activity winnowed out the upper portion of the bar finger sand, producing a well sorted, "clean" deposit. Mud was deposited in abandoned channels, swamps and delta forsets, of which only the former was recognized in the field. Extensive cover in this area conceals mudstones and stratigraphic relationships. However, the geographic positions of the Chadborn and Clyde Park exposures strongly suggests these deposits are correlative with the middle fine grained portion of the Area Creek and Brackett Creek sections. Therefore, during middle Fort Union deposition the epicontinental sea extended as far west as the Shields River.

At the top of the Brackett Creek section on Nixon Peak a 150 meter thick deposit of the conglomeratic facies overlies Area Creek type sandstones. Similarly the top of the Area Creek section contains several thick, coarse-grained sand lenses (Fig. 26). These isolated remnents are the youngest preserved sediments and record the progradation of a coarse clastic wedge over the fine grained middle Fort Union. The Nixon Peak conglomerates contain approximately 5 percent limestone clasts suggesting extensive uplift of a nearby carbonate highland, possibly the Bridger Range. Additionally, several clasts of suspected Beltian sediments were collected from this coarse horizon. The history of basin filling above the upper conglomerate is unknown because the top of the Fort Union is everywhere an erosion surface.

CHAPTER V

URANIUM IN THE FORT UNION

A scintillometer was used to measure the radioactive emissions of Fort Union outcrops. Although scintillometer readings were recorded at many locations, the instrument was only available for part of my field work, limiting this portion of the study. Typical background radiation levels ranged from 45 to 75 c.p.s. The highest reading observed was 125 c.p.s. at the base of a large sandstone lens (in SE 1/4 S2, T2S, R8E) containing organic debris and clay rip-up clasts. Figure 27 illustrates the variation in scintillometer readings in an Area Creek fining upward sequence. Generally the highest readings are associated with the basal, organic rich scour troughs and there is a steady decline in emissions as the sandstone fines upward. Although the scintillometer readings are low, the variation reported above suggests that uranium was concentrated to some degree in porous organic and clay rich horizons.

Forty samples of sandstone, mudstone, coalified wood and Maudlow volcanic rocks were prepared for geochemical analysis by the Los Alamos Lab. This data, when available, should provide 1) an indication of the amount of uranium versus other radioactive nucleids, making scintillometer readings more meaningful, 2) an overall estimation of the uranium contained in Fort Union sandstones, and 3) the uranium content of the volcanic source rocks.

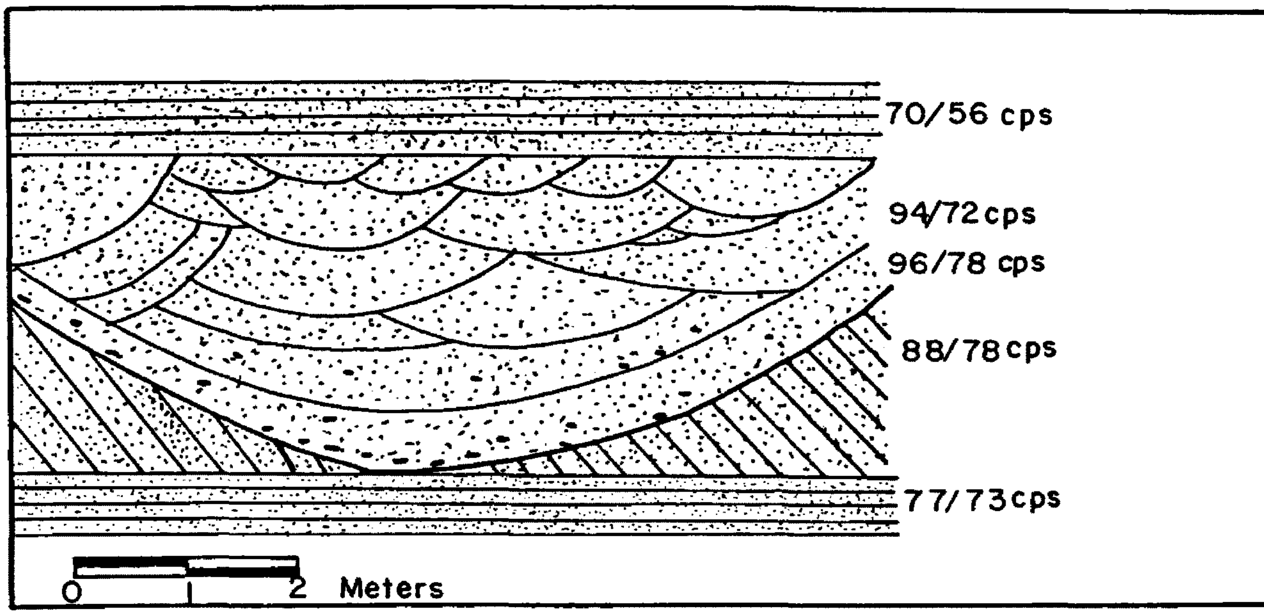

Figure 27 Variation in scintillometer readings in a fining upward sequence, Area Creek-type sandstone. Exposed at location 26 Appendix Figure B.

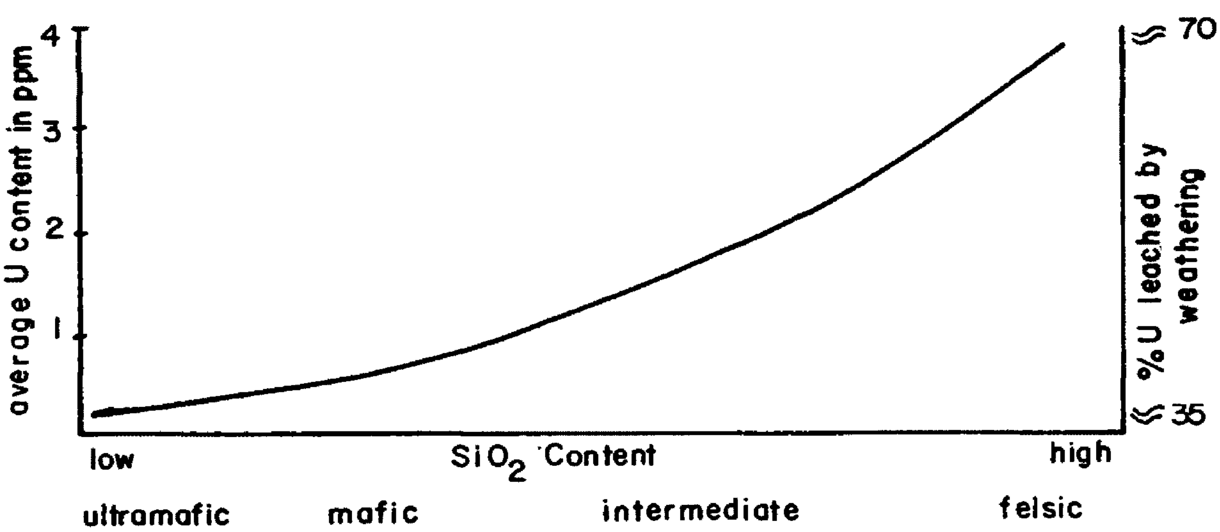

Figure 28 Average uranium content and leachability of igneous rocks. Modified from data in von Backstrom,(1974) and Larsen and Gottfried, (1961).

The depositional environments recognized within the Fort Union Formation are very similar to those which deposited the uranium-bearing host rocks in the Wyoming Basins and Colorado Plateau. In order to form sandstone-type uranium deposits within these favorable sedimentary environments a uranium source, transportation system and precipitation mechanism is required. The uranium source for the generalized model discussed in Chapter I is the intrinsic uranium within granitic and tuffaceous host sandstones as well as the extrinsic uranium supplied by leaching nearby granites. Because of the large ionic radius, odd coordination requirements and large electrical charges, uranium ions will not substitute for common cations in rock forming minerals. This leads to the progressive partitioning of uranium into late stage siliceous melts (Fig. 28). Uranium in igneous rocks occurs as 1) leachable uranium minerals, 2) refractory high temperature uranium minerals, 3) leachable molecular or ionic disseminations within volcanic glass, common minerals and intergranular cavities (Armstong, 1974). Basic igneous rocks commonly contain less than 1 ppm uranium, the majority of which occurs in refractory, nonleachable minerals. Felsic rocks are a more favorable source, containing 3 to 12 ppm uranium (Bowie, 1970) much of which is easily leachable under surface conditions. Volcanic ash typically contains high concentrations of many metals and has long been cited as the uranium source for sandstone type deposits. The alteration of volcanic glass to smectite releases uranium to diagenetic waters (Walter and Granger, 1953).

The volcanic detritus within the Fort Union Formation is primarily andesitic in composition although some felsic tuff is present. The low ash content and presumable low uranium content of the andesitic detritus most likely precludes the intrinsic uranium source for Fort Union sandstone mineralization. Forthcoming Los Alamos geochemical analyses of Fort Union sandstones may substantiate this opinion.

Roberts (1972) reports the occurrence of several thousand meters of Eocene andesitic and dacitic igneous rocks and volcaniclastic sediments south of Livingston. Most units thin northward and are truncated by a post Eocene erosion surface. These rocks may once have overlain the Fort Union Formation, however, the Eocene andesites may also contain insufficient leachable uranium to form an economic deposit.

Glancy (1964) reports the occurrence of late Tertiary ash beds east of Bozeman (R6E, T2S). These pyroclastics may have once covered the Fort Union Formation and during devitrification possibly provided uranium to circulating groundwaters. This hypothesis is analogous to some of the proposed origins of the Colorado Plateau and Wyoming Basin uranium deposits (Walter and Granger, 1953).

Probably the most favorable uranium source is the Eocene Crazy Mountains alkaline intrusive series. Due to partitioning of uranium into late stage melts, alkaline rocks are commonly enriched in this metal. Uranium concentrations in some alkaline rocks may average 200 to 600 ppm (Bohse, 1974). A large sill of the Crazy Mountain series (Gobblers Knob) intruded Fort Union strata within the study area (Fig. 5).

Scintillometer measurements on this intrusive were 125 c.p.s., twice the typical background readings of Fort Union sandstones. The main intrusives are located east of the study area and have domed and metamorphosed the surrounding Fort Union sediments. Conceivably the Crazy Mountains intrusives may contain (or have contained) a significantly large, readily leachable supply of uranium which could be transported into domed Fort Union sandstones by circulating groundwaters.

Working with chemical, thermodynamic data, Hosteller and Garrels (1962) constructed phase diagrams for chemical systems believed to be operative during uranium transportation and precipitation. They concluded that regardless of source, uranium in the supergene environment is probably transported in the hexavalent state, as a carbonate complex such as $[UO_2(CO_3)_3]^{-4}$ and $[UO_2(CO_3)_2 \cdot 2H_2O]^{-2}$. Ore-bearing fluids are neutral to alkaline, mildly reducing, natural groundwaters, containing uranium in ppb concentration levels. Uranium transportation is favored by high CO_3 concentrations (Hosteller and Garrels, 1962). The majority of Fort Union sediments were deposited and diagenetically altered under reducing conditions, as witnessed by the common abundance of preserved organic debris. Furthermore, the occurrence of authigenic clinoptilolite suggests that diagenetic groundwaters were slightly alkaline (Hay, 1966). Within this favorable environment, volcanic debris underwent alteration, releasing K, Na, Ca, Mg, Fe and Si, forming authigenic clays and extensive silica cementation. Despite the iron rich reducing environment, Fort Union sandstones are disturbingly deficient in pyrite, a ubiquitous constituent of uranium host rocks. Fort Union sandstones contain above average quantities of magnetite, which is generally deficient in uranium-bearing host rocks (Rackley, 1976). Some magnetite grains are euhedral, suggesting that iron was incorporated into magnetite and serpentine, rather than pyrite, during diagenesis. Syntaxial overgrowths on detrital magnetite grains could also form euhedral crystals. Figure 29 shows magnetite forms only under extremely basic conditions. However, if both carbonate and sulfur concentrations are very low the field of magnetite expands into the near neutral environment (Krauskopf, 1967). Most thin sections contain only small quantites of calcite cement which apparently precipitated after the pervasive silica cementation. The initial diagenetic environment was probably deficient in carbonate and sulfur. Intrinsic uranium released during ash devitrification may have been unable to form carbonate complexes, a situation clearly unfavorable for the formation of sandstone type uranium deposits. Sandstones from the top of the Area Creek section and near Chadborn contain extensive calcite cementation. Extrinsic uranium, leached from the hypothesized late Tertiary tuffs and/or the Crazy Mountain intrusives may therefore have had a more favorable chemical environment.

Some of the olive green sandstones which outcrop in the lower Area Creek section have been locally bleached to a yellowish gray (5Y 8/1). The yellowish sandstones are porous, poorly indurated and in thin section, hematite stained. No significant differences in scintillometer readings were recorded between the yellowish and olive green sandstones. Samples

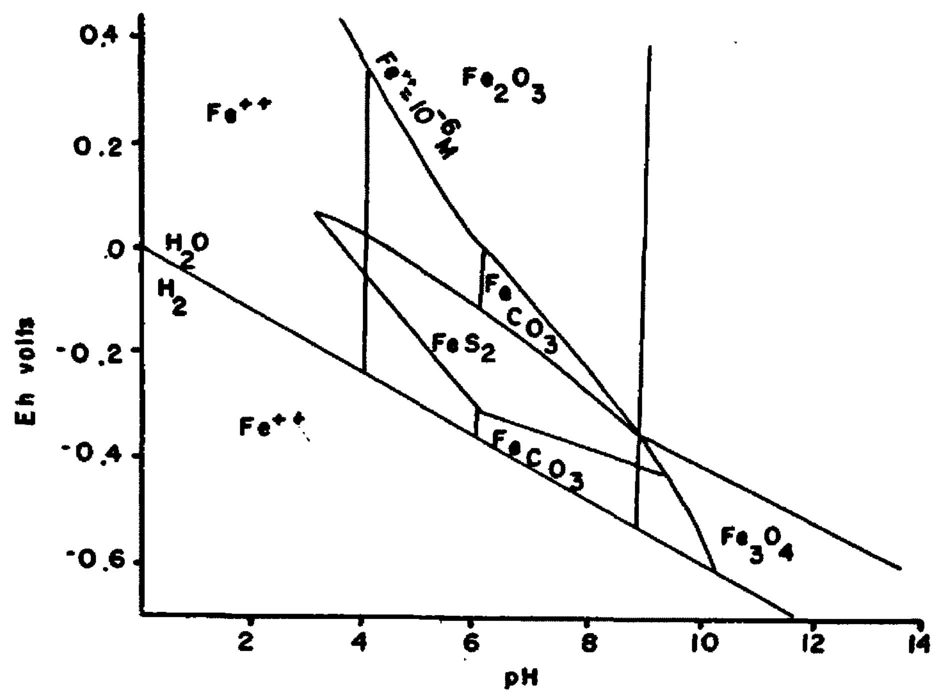

Figure 29 Eh-pH diagram showing stability fields of common iron minerals. Total dissolved sulfur 10^{-6}M, dissolved carbonate 1M. From Garrels and Christ, 1965, p224.

of both sandstones are being analyzed for elemental differences. Yellowish-gray zones probably result from differential cementation, a feature not uncommon to terrestrial deposits. The poorly cemented sandstone may be more susceptible to present day weathering, causing the oxidation of ferrous iron minerals.

The bleaching may also have formed by the influx of oxygeneated surface waters during diagenesis. However, alteration zones produced by geochemical cells are most easily identified in the subsurface and are almost impossible to recognize in weathered outcrops (Rackley, 1976).

The most prevalent hypothesis for the precipitation of uranium minerals involves the reduction of soluable U^{+6} to insoluable U^{+4} by organic matter and H_2S, along the margin of a geochemical cell. The most commonly formed minerals are uraninite (UO_2) and in the presence of vanadium, carnotite ($K_2(UO_2)_2\ (VO_4)_2 \cdot 3H_2O$) (Hosteller and Garrels, 1962). In recent years many authors have recognized that bacteria provide a fundamental control on the chemical environment developed during the migration of geochemical cells (Rackley, 1976). The complex reactions which probably occur along the margins of advancing geochemical cells are illustrated in Figure 30. Within a sedimentary sequence uranium precipitation most commonly occurs along the margins of porous, organic rich channel sandstones, complexly interbedded with impervious mudstones (Fisher, 1974, Gabelman, 1971).

The conglomeratic facies of the Fort Union lacks the carbonaceous trash and interbedded mudstones essential for the precipitation of

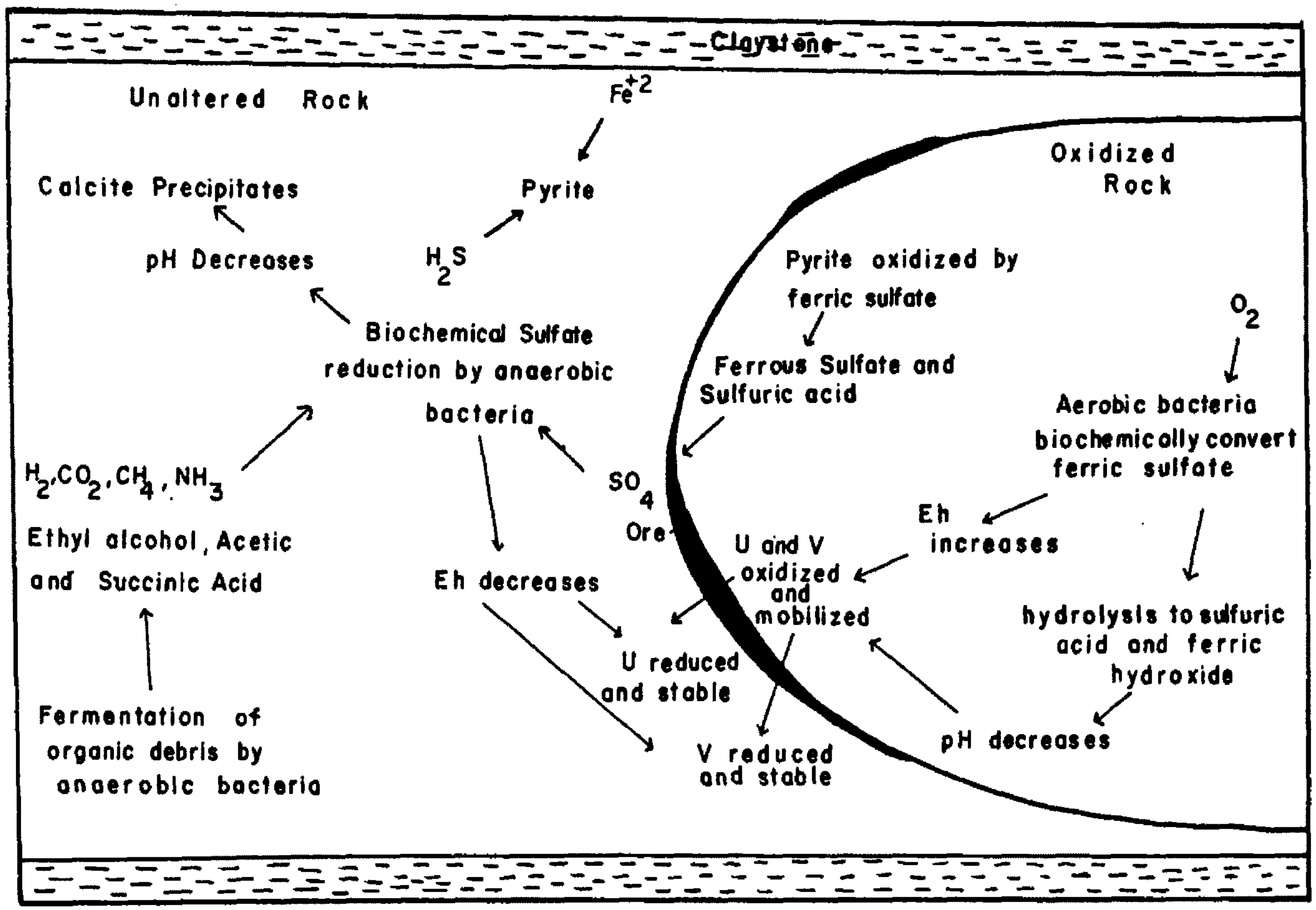

Figure 30 Probable reactions in an advancing geochemical cell, from Rackley, 1976.

uranium, and is therefore unlikely to host these deposits. The complex interbedding of organic rich, lensoidal sandstones with flood plain and abandoned channel mudstones in the Area Creek, Brackett Creek and Chadborn facies provides a sedimentary environment favorable for uranium precipitation. However, sandstones within these facies lack pyrite; an important chemical component in geochemical cell reactions. If the reactions portrayed in Figure 30 are correct, the absence of pyrite may preclude the extensive precipitation of uranium.

The model developed above may explain the apparent lack of uranium mineralization within the Fort Union Formation. Alternately one can build strong arguments postulating potential uranium resources within these strata. The depositional environments recognized in the Fort Union Formation are remarkably similar to those active during the sedimentation of known uranium-bearing sandstones. Although andesites generally contain less uranium than felsic rocks, and are often cited as a poor source of uranium, the Elkhorn volcanic field probably contains (or contained) more than enough uranium to form economic occurrences. Prior to the uplift of the Bridger Range (possibly time equivalent to the upper Fort Union conglomerate) surface and groundwaters probably flowed from the Elkhorn field into the Crazy Mountain basin. Weathering of the Elkhorn volcanics may have provided significant quantities of uranium to circulating groundwaters.

The lack of pyrite in Fort Union sandstones may not preclude the precipitation of uranium ions from oxidized waters. The oxidation of pyrite supplies sulfate, utilized by anaerobic bacteria. The bacteria maintain reducing conditions favorable for uranium precipitation (Fig. 30). Hot springs associated with the Elkhorn volcanic field may have supplied sulfate to circulating groundwaters, maintaining bacteria populations, providing an environment conducive to uranium precipitation. H_2S derived from coals in the Livingston Group and Eagle sandstone could also precipitate uranium from solutions with the Fort Union Formation (Jensen, 1958).

Based on the information available from surface exposures, both models are equally plausible. Further exploration involving radiometrics and drilling are required to resolve this dilemma.

CHAPTER VI

CONCLUSIONS

The Fort Union Formation in the Crazy Mountains basin is a syntectonic series of coalessing alluvial fans deposited marginal to a highland containing andesitic volcanics, quartzites, Paleozoic carbonates and Precambrian basement rocks. Streams carrying detritus from these sources prograded southeastward over Livingston Group delta-flood plain sediments. Braided streams on the apical high gradient portion of the alluvial apron deposited the conglomeratic facies exposed in the northwest portion of the study area. Further down the fan moderately sinuous, mixed load streams deposited fining upward sand lenses and extensive flood plain muds of the Area Creek facies. This facies interfingers laterally with distributary channel and delta topset marsh deposits of the Brackett Creek facies on the low gradient distal portion of the alluvial apron. At the eastern margin of the study area delta distributary channels deposited the Chadborn bar finger sands, marginal to an extensive epicontinental sea.

Economic Potential

The economic potential of the Fort Union Formation in the western Crazy Mountains Basin is not fully understood. No uranium has been found and background radiation levels of surface materials are low. Fort Union sediments derived primarily from andesitic extrusives probably contain insufficient leachable uranium to form an economic deposit. The absence of granitic detritus and extensive ash horizons within the Fort Union probably eliminates the intrinsic source for mineralization.

Late Tertiary ash deposits may once have overlain the Fort Union Formation and supplied uranium to circulating groundwaters. The Crazy Mountains alkaline series, east of the study area is probably the most favorable source of uranium in this region.

As part of the NURE program stream sediments and water samples, collected from the Bozeman 2° sheet, were analyzed by the Los Alamos Laboratory. Figure 31 illustrates the uranium contents of surface waters flowing over the Fort Union Formation. Streams draining the Crazy Mountains intrusives contain less dissolved uranium than those draining the Fort Union; apparently contradicting the Crazy Mountains uranium source hypothesis. However, the uranium content of surface waters is a function of water geochemistry, hydrology, topography and climate in addition to the availability of uranium in the drainage area (Bolivar, 1979). Surface waters draining mountainous regions typically are low in dissolved solids and therefore have short uranium dispersion trains (Bolvair, 1979). Streams in low lying basins have higher dissolved solids and therefore relatively higher uranium concentrations. I suggest the low uranium values exhibited by surface waters draining the Crazy Mountain intrusives are not indicative of low uranium concentrations within these rocks.

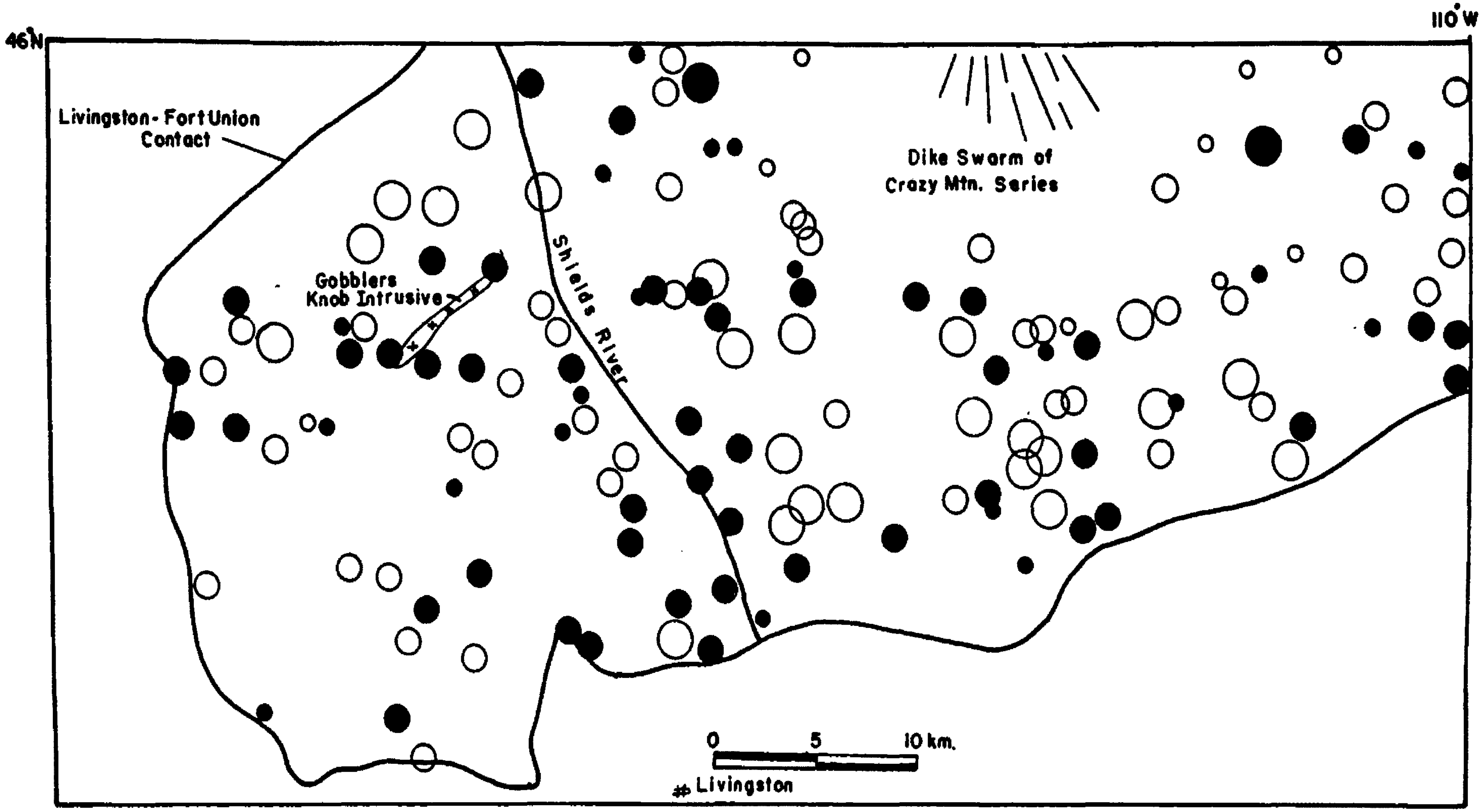

Figure 31 Uranium concentrations in streams draining the Fort Union Formation, from Bolivar (1979), plate 3

Concentrations in ppb ○ 0.0-0.2, ● 0.2-0.5, ○ 0.5-1.0, ● 1.0-2.0, ○ 2.0 5.0, ● 5.0 - 10.0.

The structural deformation and diverse sedimentary environments within the Fort Union alluvial apron provide favorable settings for the development of geochemical cells. Based on the authigenic mineralogy of Fort Union sandstones, the diagenetic environment was reducing, mildly alkaline and carbonate and sulfur deficient. The lack of carbonate is unfavorable for the transportation of uranium ions. Although abundant organic matter is present in the Fort Union, the absence of pyrite may prevent the precipitation of uranium by biological processes. However, other sources of sulfate or H_2S may have been able to precipitate uranium from oxidized groundwater.

Future uranium exploration in the Fort Union Formation should be conducted near the preiphery of the Crazy Mountains Intrusives. The general paucity of outcrops throughout the Crazy Mountain Basin will necessitate the use of radiometrics and drilling to delineate favorable targets.

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Appendix

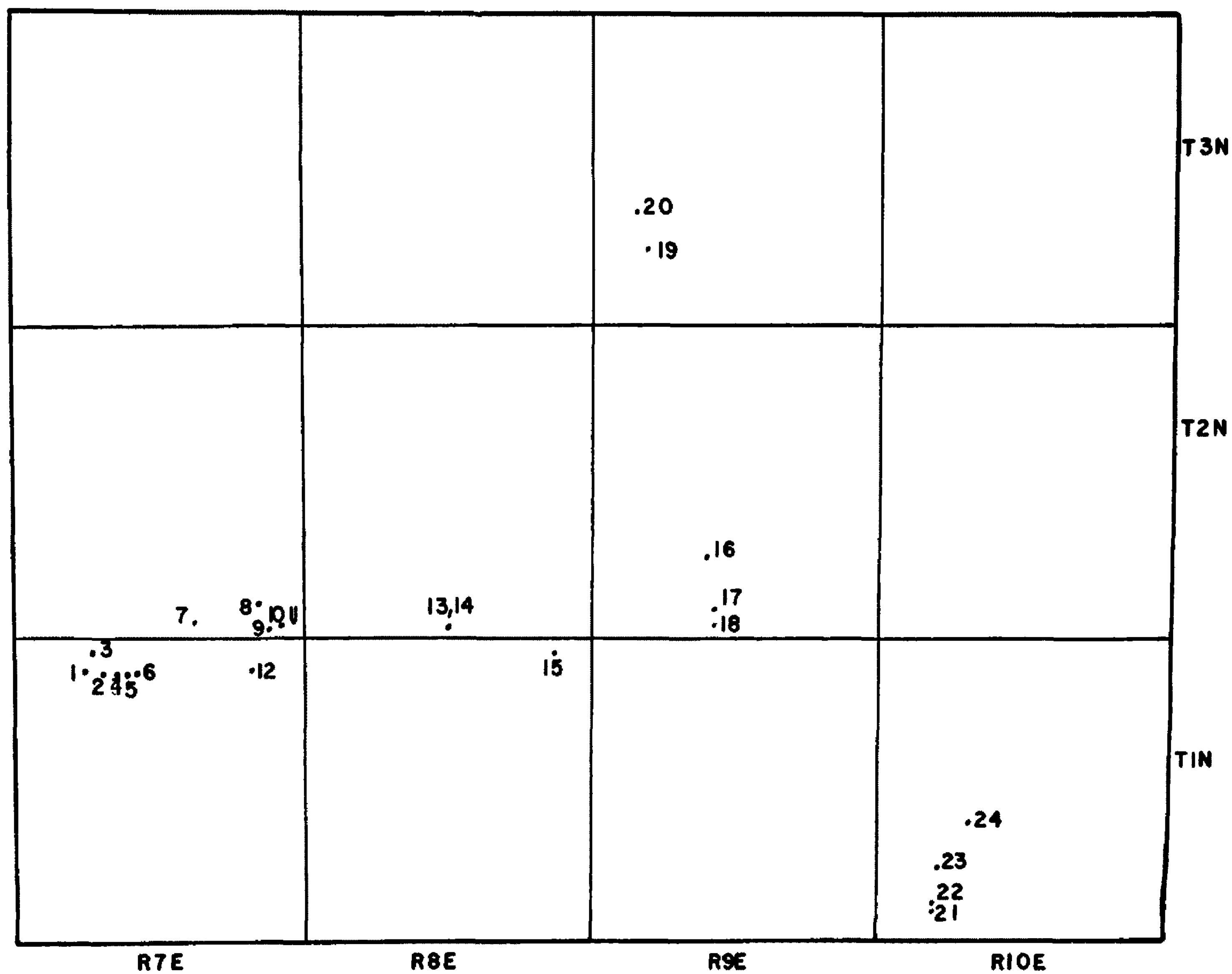

Figure A Battle Ridge, Brackett Creek, Wilsall, Clyde Park and Chadborn thin section location map.

Table A. Mineralogical compositions of thin sections from Battle Ridge, Brackett Creek, Wilsall, Clyde Park and Chadborn
See Figure A for locations

Thin Section #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
quartz	8	15	14	28	20	25	20	10	18	25	20	33	25	25	30	25	20	24	40	18	60	20	21	30
composite quartz	1M	PSM	PM	PS	PSM	PM	PMS	PSM	PS	PM	PM	0	P	PSM	PS	PM	0	PS	PM	PS	PM	PM	1SM	PS
plagioclase	1	1	1	2	1	1	5	P	2	P	P	1	2	1	2	P	0	3	2	3	1	1	P	P
orthoclase	2	2	3	2	3	4	1	0	3	0	2	2	3	3	4	0	0	2	2	2	2	3	3	1
volc. rock frag.	75	63	71	47	64	56	57	74	61	43	55	32	60	65	57	50	0	56	39	48	25	62	56	40
augite	6	2	2	5	P	6	5	1	4	18	6	P	2	1	P	2	P	P	0	P	P	1	P	P
limestone clasts	0	0	0	0	0	0	0	12	0	0	0	20	0	0	0	0	70*	0	1	23	0	P	3	0
biotite	0	0	P	0	P	0	P	0	P	0	0	P	P	P	0	0	P	2	P	0	P	P	P	P
chlorite	0	P	0	0	0	0	0	0	0	0	0	0	P	0	P	0	P	1	0	0	P	P	0	P
opaques	1	1	P	3	P	4	1	P	2	2	3	P	2	P	1	6	2	3	7	P	2	3	1	4
calcite cement	P	P	0	1	0	P	0	0	0	P	P	2	1	P	4	12	*	4	1	2	2	2	12	14
silica cement	15	14	9	12	11	4	10	3	10	12	14	10	5	10	6	5	0	5	8	3	6	8	4	11
max. grain size mm	1.2	1.1	12	8	.75	1.3	1.9	4	.9	.8	3	.5	.7	.5	1.0	.3	.2	.25	.5	6	.2	.4	1.1	.25
min. grain size mm	.2	.2	.2	.2	.15	.2	.2	.2	.2	.2	.1	.2	.1	.1	.2	.1	.1	.1	.1	.3	.1	.1	.1	.1
sorting	2	2	0	1	2	2	1	0	2	2	1	3	2	2	3	2	3	3	2	0	3	2	0	3
% angular qtz grains	75	70	90	65	40	65	30	80	75	30	30	30	25	50	60	75	80	25	15	20	20	40	35	60
average An content of plagioclase	36	30	31	29	30	32	30	38	38	35	35	33	33	38	33	34	-	33	36	33	33	40	37	31
amount of hematite staining	M	M	H	M	H	M	M	M	H	M	S	M	M	S	M	H	M	M	H	M	M	H	M	M

sorting 0 = poor
1 = fair
2 = moderate
3 = well sorted
4 = excellent

hematite staining S = slight
M = moderate
H = heavy

P = mineral present less than 1%
* = limestone, non clastic rock
composite quartz S = sedimentary quartz grains
M = metamorphic quartz grains

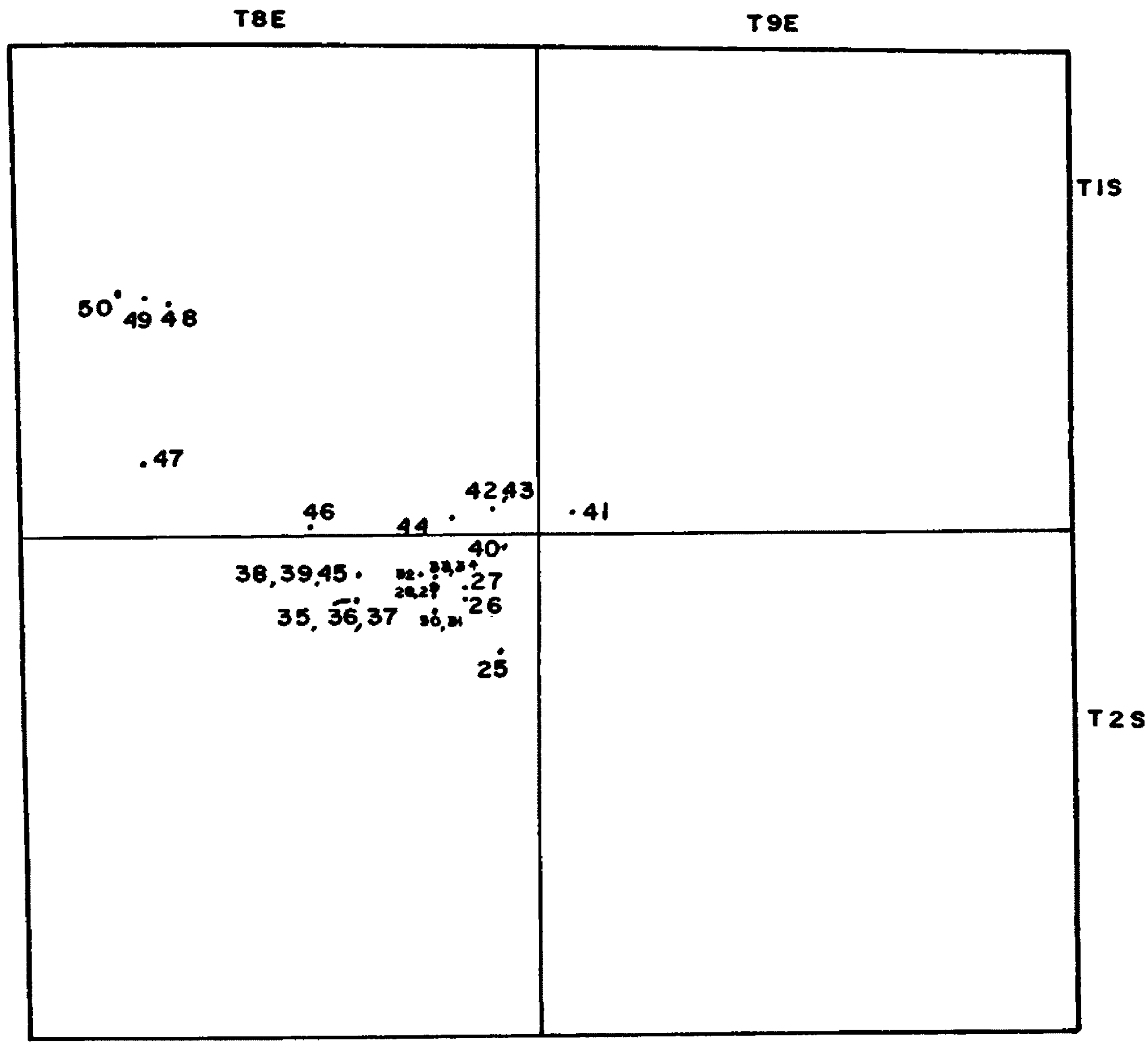

Figure B Area Creek thin section location map.

Table B. Mineralogical compositions of thin sections from Area Creek. See Figure B for locations

Thin Section #	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
quartz	7	39	13	20	46	40	28	25	29	25	15	40	40	25	30	30	27	20	35	10	45	50	25	28	35	20
composite quartz	0	1S	PSM	PS'	PMS	PS	PMS	PM	PM	PS	0	PM	PM	2S	PS	PS	0	0	PMS	0	PS	PS	PM	PM	0	PMS
plagioclase	1	1	2	3	1	P	2	6	2	6	P	2	2	5	4	2	2	1	4	0	4	1	2	1	2	2
orthoclase	3	2	4	1	2	0	2	0	3	3	5	1	2	0	1	0	P	0	0	0	5	1	2	2	1	2
volc. rx frag.	72	41	67	70	44	50	53	53	57	53	72	44	45	58	55	37	41	3	48	0	29	32	2	45	48	51
augite	6	3	2	P	3	P	P	1	P	3	P	1	1	P	P	P	1	P	1	P	1	P	46	7	1	1
limestone clasts	0	1	0	0	0	P	P	2	1	5	0	2	0	3	2	1	2	20	4	P	4	2	0	2	2	2
biotite	0	P	P	P	0	0	P	0	0	0	P	0	P	0	P	P	P	0	P	P	P	0	P	0	P	0
chlorite	0	P	0	0	0	P	0	P	P	0	0	P	P	0	0	0	P	0	0	P	P	0	0	P	0	P
opaques	1	2	1	P	P	P	P	2	2	P	1	1	1	P	0	P	2	1	2	P	P	1	P	1	P	2
chalcedony	0	0	0	0	0	P	0	P	0	P	0	0	P	P	P	0	P	0	0	0	P	0	0	0	P	0
calcite cement	0	P	0	0	0	2	0	5	1	0	0	2	1	2	2	4	20	50*	4	90*	2	3	16	4	2	20
silica cement	9	8	11	6	4	8	15	5	5	8	8	6	8	5	6	6	5	0	P	0	0	10	5	10	8	0
max grain size in mm	4	1	3	3.5	.6	3	5	1.2	1	1.2	1	.8		1.2	1.5	2	1	.3	.5	.1	1	.6	.8	.5	.4	.7
min grain size in mm	.2	.2	.2	.2	.1	.2	.2	.2	.2	.2	.1	.2	.2	.2	.2	.2	,1	.1	.1	.05	.2	.2	.2	.2	.1	.1
sorting	0	2	0	0	2	2	2	0	2	0	2	3	0	0	0	2	2	3	2	3	2	2	0	2	2	1
% angular qtz grains	20	45	60	70	25	50	65	60	50	60	50	75	85	40	35	30	70	75	65	80	30	60	85	70	60	80
average An content of plagiozlase	37	34	39	32	30	27	38	27	28	39	33	31	39	32	35	35	38	33	32	-	37	31	33	30	28	34
amount of nematite	H	H	H	S	M	M	S	H	S	S	H	S	S	H	S	S	M	O	M	O	S	S	H	H	H	H

Key - hematite staining S-slight
M-moderate
H-heavy

P-mineral present less than 1%
*-limestone-non-clastic rock
composite quartz - S-sedimentary rock fragments

Sorting 0 = poor
1 = fair
2 = moderate
3 = well sorted
4 = excellent sorting

M = metamorphic rock fragments

ADDENDUM

The Los Alamos Scientific Laboratory geochemically analyzed 40 whole rock samples; the results of which arrived after the completion of this project.

No anomalous uranium or uranium path finder elemental concentrations were reported. Mudstones generally contain the highest uranium concentrations, ranging from 2.06 to 2.97 ppm; mean value 2.31 ppm and average value 2.42 ppm. Sandstones display a broader range of uranium concentrations, 1.40 to 3.59 ppm, but as a group have lower mean (1.99 ppm) and average (2.01) values. The higher mean and average uranium contents of the mudstones probably results from uranium's affinity for organic matter and clay minerals. Alternately surface weathering may have leached uranium from the porous and permeable sandstones and may have had little effect on the impervious mudstones.

Figure 27 portrays the variation in scintillometer readings in a fining upward sequence. Samples were analyzed from each scintillometer station. From the base of the sequence to the top the sample numbers are (3270) 43, 37, 44, 63 and 62. Sample 44, a coarse grained sandstone containing abundant clay rip-up clasts from the base of a large scour channel had the highest reported uranium content of the entire study, 3.28 ppm. A cleaner finer grained sandstone (sample 63) .6 meters above sample 44 contained 2.31 ppm uranium. Above this sample finer grained silty mudstones contained 2.49 ppm uranium. These five samples suggest uranium is preferentially concentrated in the clay rich basal channel lag sandstones and fine grained mudstones. Figure 27 also suggests that no direct relationship exists between the scintillometer readings and the uranium concentrations. The highest scintillometer reading is associated with the highest uranium analysis (sample 44). However, a reading only 8 cps lower is associated with a sample (#37) containing half the uranium and a sixth the thorium. Thorium may be responsible for some of the variation, however, most of the variance is probably due to the scintillometer's inability to selectively measure radiation from a single point.

Three fossilized wood samples (#49, 65 and 68) contained the lowest uranium concentrations of the 40 sample tested (1.00, .67 and .52 ppm uranium). This relationship is opposite that of uraniferous districts where carbonaceous materials are often highly enriched in uranium compared to the surrounding sandstones. Groundwater flowing through the Fort Union apparently was unable to remobilize, transport and concentrate significant amounts of uranium in organic rich materials.

A sample of an intermediate volcanic flow from the Maudlow Formation (sample #41) contained 1.28 ppm uranium. Although only one sample of suspected source rock was analyzed, this rock type is lithologically representative of Fort Union detritus and possibly indicative of a poor source of uranium ions.

Although limited in scope and possibly effected by surface weathering the results of the whole rock geochemical investigation suggests that the Fort Union Formation is unlikely to host significantly mineralized strata in this area.

Listings of Field Data and Elemental Concentrations

for Rock, Soil, and Sediment Samples from University of Montana

Pilot Studies in Western Montana and East-Central Idaho

(48 pages)

Note that four pages, numbered (1) through (4) in the upper right hand corner, are necessary to provide the complete data listing for each numerically ordered sequence of samples.

- (1) - Lists field data and uranium concentrations determined by Delayed-Neutron Counting.
- (2) - Lists concentrations of 11 elements determined by X-Ray Fluorescence and Arc-Source Emission Spectrography.
- (3) and (4) - List concentrations of 31 elements determined by Neutron Activation Analysis and computed U/Th ratios.

(See Attachment 3 for Code to Listings)

DESCRIPTION
OF
UNIVERSITY OF MONTANA PILOT STUDIES

(SEE ATTACHMENTS 1, 2, AND 3 FOR FIELD AND ANALYTICAL DATA)

AREA NUMBER	SAMPLE NUMBERS	GEOGRAPHIC LOCATION	NO. OF SAMPLES	SAMPLE TYPE(S)	STUDY TOPIC
1	327001-327030	Southern Highland Mt. area in Madison Co., MT, 50 km south of Butte.	30	Rock	Uranium and thorium distributions in upper amphibolite facies metamorphic rocks of the Cherry Creek group.
2	327031-327070	Grassy Mt.-Gobblers Knob area in Park Co. and Gallatin Co., MT, 10 km northwest of Livingston.	40	Rock	Relation of uranium and other metals to carbonaceous materials and sedimentary structures in sandstones of the Ft. Union formation on the western margin of the Crazy Mt. basin.
3	327071-327091	Sapphire Mt. area in Ravalli Co., MT, 70 km northeast of Hamilton.	21	Rock	Distribution of uranium, thorium, and other trace elements in a differentiated alkaline ultramatic/syenitic igneous complex.
4	327092-327186	Bitterroot Mt. area in Idaho Co., ID, along Lochsa River and Bear Creek.	95	Rock	Variations in uranium and thorium contents across two major and several minor granitic plutons at the northern end of the Idaho batholith.
5	327187-327269	Highwood Mt. area in Choteau Co., MT, 70 km east-northeast of Great Falls.	83	Rock	Behavior of uranium, thorium, and other trace elements during differentiation of alkali-rich basaltic rocks from the Shonkin Sag laccolith and related rocks of the Highwood Mt. igneous province.
6	327270-327579	Bitterroot Mt. area in Ravalli Co., MT, 10 km southwest of Conner.	310	Stream Water, Stream Sediment, Soil, and Rock	Comparisons of uranium contents in soils and stream sediments with the felsic plutonic rocks from which they were derived. This study also examines variations of uranium concentrations in stream waters as a function of seasonal fluctuations.
7	327580-327637	Ruby, Gravelly, Madison, Gallatin, and Absaroka Ranges in Southwestern Montana.	58	Rock	Regional distribution of uranium, thorium, and other trace elements in high-grade Archean metamorphic rocks of southwestern Montana with emphasis on the possible mobilization and migration of the radioactive elements with increasing metamorphic grade.
8	327638-327733	Flint Creek Mt. area in Granite Co. and Powell Co., MT, between Phillipsburg and Deer Lodge.	96	Rock	Patterns of uranium distribution in felsic plutonic rocks of the Royal, Phillipsburg, Mt. Powell and Racetrack Creek plutons of the Flint Creek instrusive complex.

DOE SAMPLE NUMBER						LASL SAMPLE LOCATION NUMBER AND FIELD DATA																												U CONCENTRATION
STATE	LATITUDE	LONGITUDE	DOE LAB	SAMPLE TYPE	REPLICATE	LASL SAMPLE LOCATION NUMBER	TIME SAMPLED DATE	TIME SAMPLED HOUR	AIR TEMPERATURE	WATER TEMPERATURE	COMMENTS	SPECIAL MEASUREMENTS	pH	CONDUCTIVITY (µmho/cm)	SCINTILLOMETER (eU, ppm)	ROCK TYPE	ROCK COLOR	SEDIMENT TYPE	SEDIMENT COLOR	WATER FLOW	WATER LEVEL	WATER COLOR	STREAM CHANNEL	VEGETATION TYPE	VEGETATION DENSITY	RELIEF	WEATHER	OWNERSHIP	CONTAMINANTS	WELL TYPE	WELL DIAMETER (INCHES)	WELL DEPTH (FEET)	WATER DEPTH (FEET)	SEDIMENT SAMPLES ANALYZED BY DELAYED NEUTRON COUNTING (DNC) UNITS IN ppm
30	45.5683	112.4872	2	99	0	327001	09/29/78	14	28		C				7	2	8							4	3	4	2		1					0.39
30	45.5683	112.4881	2	99	0	327002	09/29/78	14	29		C				20	2	7							4	3	4	2		1					5.79
30	45.5678	112.4973	2	99	0	327003	09/29/78	14	28		C				11	2	7							4	3	4	2		1					2.32
30	45.5647	112.4939	2	99	0	327004	09/29/78	14	29		C				0	2	9							4	3	4	2		1					0.09
30	45.5647	112.4925	2	99	0	327005	09/29/78	14	28		C				20	3	1							4	3	4	2		1					1.12
30	45.5639	112.4917	2	99	0	327006	09/29/78	15	28		C				18	2	7							4	3	4	2		1					2.15
30	45.5631	112.4911	2	99	0	327007	09/29/78	15	28		C				13	2	9							4	3	4	2		1					0.69
30	45.5644	112.4900	2	99	0	327008	09/29/78	15	28		C				7	2	8							4	3	4	2		1					0.14
30	45.5564	112.4839	2	99	0	327009	09/29/78	16	28		C				26	2	7							4	3	4	2		1					12.34
30	45.5650	112.4839	2	99	0	327010	09/29/78	16	29		C				5	2	9							4	3	4	2		1					0.53
30	45.5553	112.4847	2	99	0	327011	09/29/78	17	28		C				7	2	6							4	3	4	2		1					5.17
30	45.5661	112.4850	2	99	0	327012	09/29/78	17	29		C				26	2	7							4	3	4	2		1					7.67
30	45.5703	112.4861	2	99	0	327013	09/29/78	17	28		C				7	2	7							4	3	4	2		1					0.24
30	45.5697	112.4842	2	99	0	327014	09/30/78	9	23		C				5	2	7							4	3	4	2		1					0.27
30	45.5686	112.4917	2	99	0	327015	09/30/78	10	23		C				3	2	7							4	3	4	2		1					0.40
30	45.5686	112.4919	2	99	0	327016	09/30/78	10	23		C				14	2	1							4	3	4	2		1					3.21
30	45.5686	112.4822	2	99	0	327017	09/30/78	10	23		C				3	2	7							4	3	4	2							1.11
30	45.5686	112.4825	2	99	0	327018	09/30/78	10	23		C				18	2	6							4	3	4	2		1					2.61
30	45.5692	112.4817	2	99	0	327019	09/30/78	12	24		C				26	2	7							4	3	4	2		1					1.82
30	45.5689	112.4806	2	99	0	327020	09/30/78	12	24		C				7	2	8							4	3	4	2		1					0.43
30	45.5689	112.4803	2	99	0	327021	09/30/78	13	24		C				26	2	7							4	3	4	2		1					2.02
30	45.5675	112.4792	2	99	0	327022	09/30/78	13	24		C				13	2	8							4	3	4	2		1					0.55
30	45.5675	112.4789	2	99	0	327023	09/30/78	13	24		C				37	2	7							4	3	4	2		1					0.42
30	45.5669	112.4735	2	99	0	327024	09/30/78	14	25		C				33	2	1							4	3	4	2		1					1.54
30	45.5692	112.4736	2	99	0	327025	09/30/78	14	25		C				11	2	9							4	3	4	2		1					0.63
30	45.5647	112.4750	2	99	0	327026	09/30/78	14	25		C				5	2	8							4	3	4	2		1					0.35
30	45.5644	112.4744	2	99	0	327027	09/30/78	14	25		C				1	2	9							4	3	4	2		1					0.38
30	45.5650	112.4742	2	99	0	327028	09/30/78	15	25		C				9	2	7							4	3	4	2		1					0.73
30	45.5536	112.4864	2	99	0	327029	09/30/78	15	25		C				24	2	7							4	3	4	2		1					6.73
30	45.5550	112.4881	2	99	0	327030	09/29/78	15	29		C				33	2	7							4	3	4	2		1					5.03
30	45.6928	110.7319	2	99	0	327031	07/30/78		25		C				5	1	5									4	1		1					1.99
30	45.6894	110.7125	2	99	0	327032	08/22/78	13	25		C				7	1	7									4	4		1					1.25
30	45.8700	110.6700	2	99	0	327033	09/16/78	13	25		C				10	1	5									4	1		1					2.06
30	45.6950	110.6950	2	99	0	327034	08/13/78	11	25		C				7	1	5									4	1		1					2.97
30	45.8700	110.6700	2	99	0	327035	09/16/78	12	25		C				12	1	5									4	1		1					2.51
30	45.8786	110.8197	2	99	0	327036	07/26/78	16	25		C				7	3	5									5	1		1					1.09
30	45.6875	110.6911	2	99	0	327037	09/09/78	9	25		C				8	1	6									4	1		1					1.67
30	45.8781	110.8439	2	12	0	327038	09/07/78	11	21		C				5			5	5	2	2	2	1	3	4	4	1		1					1.93
30	45.8742	110.7050	2	99	0	327039	09/15/78	17	25		C				10	1	5									4	1		1					2.25
30	45.6875	110.6911	2	99	0	327040	09/09/78	9	25		C				14	1	6									4	1		1					2.10
30	46.1311	111.0753	2	99	0	327041	09/09/78	11	25		C				6	3	4									4	1		1					1.28
30	45.8933	110.6211	2	99	0	327042	09/06/78	14	25		C				6	1	5									4	1		1					2.22
30	45.6875	110.6911	2	99	0	327043	09/09/78	9	25		C				3	1	6									4	1		1					2.46
30	45.6875	110.6911	2	99	0	327044	09/09/78	9	25		C				15	1	6									4	1		1					3.28
30	45.6894	110.7125	2	99	0	327045	06/21/78	9	25		C				5	1	1									4	1		1					2.24
30	45.7481	110.7479	2	99	0	327046	08/02/78	10	25		C				5	1	5									4	1		1					1.62
30	45.8828	110.8744	2	12	0	327047	09/07/78	18	12	16.8	C				9			5	6	2	2	1	2	4	3	4	1		1					1.86
30	45.8875	110.6175	2	99	0	327048	09/06/78	10	25		C				10	1	5									4	1		1					2.04
30	45.8875	110.6175	2	99	0	327049	09/06/78	11	25		C				6	1	8									4	1		1					1.00
30	45.8928	110.8267	2	99	0	327050	07/25/78	11	25		C				7	1	5									5	1		1					2.00
30	45.8719	110.6894	2	99	0	327051	09/16/78	14	25		C				10	1	5									3	1		1					2.65

ATTACHMENT-2. (continued). Elemental Concentrations for Sediment Samples

DOE SAMPLE NUMBER: STATE	LATITUDE	LONGITUDE	DOE LAB	SAMPLE TYPE	REPLICATE	LAB SAMPLE LOCATION NUMBER	ELEMENTAL CONCENTRATIONS DETERMINED BY X-RAY FLUORESCENCE (Concentrations reported in weight parts per million (ppm)): Ag	Bi	Cd	Cu	Nb	Ni	Pb	Sn	W	ELEMENTAL CONCENTRATIONS DETERMINED BY ARC-SOURCE EMISSION SPECTROGRAPHY (Concentrations in weight ppm): Be	Li
30	45.5583	112.4872	2	99		0-327001	-5	-5	11	79	-20	66	-5	-10	24	-1	2
30	45.5683	112.4881	2	99		0-327002	-5	-5	5	104	-20	54	41	-10	-15	-1	40
30	45.5678	112.4878	2	99		0-327003	-5	-5	-5	43	-20	24	9	-10	-15	1	29
30	45.5647	112.4939	2	99		0-327004	-5	-5	-5	114	-20	1445	-5	-10	-15	-1	1
30	45.5647	112.4925	2	99		0-327005	-5	-5	-5	18	-20	-15	16	28	-15	10	9
30	45.5639	112.4917	2	99		0-327006	-5	-5	-5	73	21	23	13	-10	-15	-1	44
30	45.5631	112.4911	2	99		0-327007	-5	-5	6	65	-20	87	-5	-10	-15	-1	53
30	45.5644	112.4900	2	99		0-327008	-5	-5	-5	26	-20	337	-5	-10	-15	-1	37
30	45.5564	112.4839	2	99		0-327009	-5	-5	-5	11	-20	35	-5	-10	-15	2	20
30	45.5650	112.4839	2	99		0-327010	-5	-5	11	155	-20	-15	-5	-10	-15	-1	-1
30	45.5653	112.4947	2	99		0-327011	-5	-5	-5	155	44	55	-5	-10	-15	-1	-1
30	45.5661	112.4850	2	99		0-327012	44	49	28	111	-20	-15	7367	-10	-15	-1	10
30	45.5703	112.4861	2	99		0-327013	-5	-5	5	-10	-20	251	-5	-10	-15	-1	9
30	45.5597	112.4842	2	99		0-327014	-5	5	-5	86	-20	763	-5	-10	-15	-1	1
30	45.5536	112.4817	2	99		0-327015	-5	-5	6	118	-20	181	-5	-10	-15	-1	4
30	45.5596	112.4819	2	99		0-327016	-5	-5	-5	104	-20	-15	-5	-10	-15	-1	5
30	45.5686	112.4822	2	99		0-327017	-5	-5	5	99	-20	50	-5	-10	-15	-1	7
30	45.5686	112.4925	2	99		0-327018	-5	-5	-5	28	20	-15	16	-10	-15	3	9
30	45.5692	112.4819	2	99		0-327019	-5	-5	-5	24	25	-15	19	-10	-15	-1	7
30	45.5689	112.4806	2	99		0-327020	-5	-5	-5	188	-20	44	-5	-10	-15	-1	4
30	45.5689	112.4803	2	99		0-327021	-5	-5	-5	25	-20	-15	13	-10	-15	-1	10
30	45.5675	112.4792	2	99		0-327022	-5	-5	-5	119	-20	73	-5	-10	-15	-1	6
30	45.5675	112.4789	2	99		0-327023	-5	-5	-5	15	-20	289	-5	-10	-15	-1	45
30	45.5669	112.4736	2	99		0-327024	-5	-5	-5	19	-20	16	-5	-10	-15	-1	10
30	45.5692	112.4736	2	99		0-327025	-5	-5	-5	21	-20	23	-5	-10	-15	1	9
30	45.5647	112.4750	2	99		0-327026	-5	-5	5	93	-20	147	-5	-10	-15	-1	3
30	45.5644	112.4744	2	99		0-327027	-5	-5	-5	108	-20	44	-5	-10	-15	-1	3
30	45.5650	112.4742	2	99		0-327028	-5	-5	-5	82	-20	-15	6	-10	-15	-1	9
30	45.5536	112.4864	2	99		0-327029	-5	7	-5	25	-20	33	-5	-10	-15	-1	14
30	45.5550	112.4881	2	99		0-327030	-5	-5	-5	48	-20	19	8	11	15	3	95
30	45.6928	110.7319	2	99		0-327031	-5	-5	-5	38	34	36	-5	-10	-15	-1	24
30	45.6394	110.7125	2	99		0-327032	-5	-5	-5	14	30	16	-5	-10	-15	-1	10
30	45.8700	110.6700	2	99		0-327033	-5	-5	-5	56	-20	23	7	-10	-15	2	11
30	45.6850	110.6950	2	99		0-327034	-5	-5	-5	58	-20	35	21	-10	-15	1	21
30	45.8700	110.6700	2	99		0-327035	-5	6	-5	51	-20	36	-5	-10	-15	-1	21
30	45.8786	110.9197	2	99		0-327036	-5	-5	-5	26	-20	-15	5	-10	-15	-1	38
30	45.6875	110.6911	2	99		0-327037	-5	7	-5	22	-20	29	5	-10	-15	1	8
30	45.8781	110.8439	2	12		0-327038	-5	6	-5	42	-20	-15	6	-10	-15	1	11
30	45.8742	110.7050	2	99		0-327039	-5	-5	-5	45	-20	17	-5	-10	-15	2	28
30	45.6875	110.6911	2	99		0-327040	-5	-5	-5	24	-20	32	-5	-10	-15	-1	15
30	46.1311	111.0753	2	99		0-327041	-5	-5	-5	33	-20	-15	-5	-10	-15	-1	17
30	45.8933	110.6211	2	99		0-327042	-5	-5	-5	56	-20	39	6	-10	-15	-1	25
30	45.6875	110.6911	2	99		0-327043	-5	-5	-5	35	-20	31	7	-10	-15	-1	10
30	45.6875	110.6911	2	99		0-327044	-5	8	8	32	-20	74	-5	-10	-15	-1	-1
30	45.6894	110.7125	2	99		0-327045	-5	-5	-5	29	-20	46	-5	-10	-15	-1	17
30	45.7481	110.7478	2	99		0-327046	-5	-5	-5	39	-20	36	9	-10	-15	-1	41
30	45.8928	110.9744	2	12		0-327047	-5	-5	-5	57	-20	61	8	-10	-15	-1	22
30	45.8875	110.6175	2	99		0-327048	-5	-5	-5	82	21	48	-5	-10	-15	-1	19
30	45.8875	110.6175	2	99		0-327049	-5	-5	-5	19	-20	-15	-5	-10	-15	-1	-1
30	45.8428	110.8267	2	99		0-327050	-5	-5	-5	34	20	21	-5	-10	-15	-1	19
30	45.8719	110.6894	2	99		0-327051	-5	-5	-5	42	-20	24	9	-10	-15	1	48

ELEMENTAL CONCENTRATIONS DETERMINED BY NEUTRON ACTIVATION ANALYSIS

Concentrations reported in weight parts per million (ppm)

DOE Sample Number (State, Latitude, Longitude, DOE Lab, Sample Type, Replicate)	Lab Sample Location Number	Al	Au	Ba	Ca	Ce	Cl	Co	Cr	Cs	Dy	Eu	Fe	Hf	K	La	Lu
30-45.5583-112.4872-2-99-	0-327001	55900	-0.14	-192	77450	22	-119	27.5	149	-2.0	6	1.6	50080	2.5	-4423	-9	0.4
30-45.5583-112.4881-2-99-	0-327002	64200	-0.15	675	14760	223	127	17.8	94	5.0	8	1.4	42710	16.5	25590	129	0.6
30-45.5579-112.4873-2-99-	0-327003	65230	-0.09	365	12930	53	-84	12.5	72	2.4	2	0.8	25460	12.1	15800	38	0.5
30-45.5547-112.4939-2-99-	0-327004	25250	-0.12	-139	30610	-6	153	71.9	2766	-1.7	-1	-0.2	48560	-1.1	-2876	-8	-0.1
30-45.5647-112.4925-2-99-	0-327005	60560	-0.06	-183	7724	25	-150	2.6	-6	5.9	6	0.1	2402	1.7	6592	14	0.4
30-45.5639-112.4917-2-99-	0-327006	60040	-0.16	684	16090	131	-101	19.2	152	5.0	5	1.1	48780	10.7	20200	68	1.0
30-45.5631-112.4911-2-99-	0-327007	65100	-0.14	307	112200	19	92	33.8	177	-2.0	4	1.2	50550	2.4	5763	-10	0.3
30-45.5644-112.4900-2-99-	0-327008	57870	-0.14	-151	83700	-6	113	42.0	1121	-2.0	2	0.7	51030	-1.2	3482	-10	-0.5
30-45.5664-112.4839-2-99-	0-327009	114000	-0.08	-140	2776	96	-61	6.9	21	4.0	2	0.4	20500	4.2	8720	63	0.2
30-45.5650-112.4839-2-99-	0-327010	8710	-0.12	-76	2073	57	-20	8.1	26	-1.7	1	-0.2	138400	-1.1	2986	-6	-0.1
30-45.5653-112.4847-2-99-	0-327011	45120	0.13	202	2501	46	-23	24.5	51	4.4	4	0.8	102400	3.8	19770	39	0.4
30-45.5561-112.4850-2-99-	0-327012	30500	0.76	153	5781	32	-28	2.7	26	29.5	2	0.5	13060	2.1	11330	18	0.2
30-45.5703-112.4861-2-99-	0-327013	64440	-0.14	-166	90720	-6	125	36.2	885	-1.9	1	-0.2	44170	-1.2	-3904	-9	0.3
30-45.5697-112.4842-2-99-	0-327014	63220	-0.19	-186	51830	15	-88	59.7	1370	-2.5	2	0.4	55460	-1.7	-3928	-12	-0.2
30-45.5536-112.4917-2-99-	0-327015	77210	-0.11	-147	74150	22	-96	34.4	252	-1.6	2	0.8	48280	1.7	-3575	12	0.3
30-45.5686-112.4810-2-99-	0-327016	64930	-0.10	579	18470	157	-93	7.2	18	-1.4	13	1.8	53430	11.8	6463	78	1.6
30-45.5686-112.4822-2-99-	0-327017	62780	-0.13	-173	58810	36	-108	28.1	95	-1.8	5	0.9	42500	2.8	-3934	21	0.4
30-45.5586-112.4825-2-99-	0-327018	53790	-0.13	631	17030	129	-108	6.4	-12	2.6	10	1.8	42790	12.5	15770	57	1.1
30-45.5692-112.4819-2-99-	0-327019	52900	-0.05	644	13500	44	-78	6.6	23	1.6	3	0.7	11400	5.8	25540	23	0.3
30-45.5589-112.4806-2-99-	0-327020	62410	-0.14	-174	62590	11	293	34.5	57	-2.0	3	0.8	68890	1.9	-4391	-10	0.4
30-45.5539-112.4803-2-99-	0-327021	66050	-0.06	1053	12130	57	-92	4.7	16	1.4	2	0.7	9838	6.7	24650	36	0.2
30-45.5675-112.4792-2-99-	0-327022	78590	-0.20	-208	81250	36	260	33.4	150	-2.8	2	0.7	50160	-1.8	-4774	-13	0.2
30-45.5675-112.4783-2-99-	0-327023	60910	-0.13	-150	108200	-5	-86	41.6	960	-1.9	1	0.3	49100	-1.1	5652	-10	0.2
30-45.5669-112.4736-2-99-	0-327024	78470	-0.07	202	-435	84	-30	8.7	24	2.9	3	1.1	5659	8.4	24720	51	0.2
30-45.5592-112.4736-2-99-	0-327025	99060	-0.07	209	3000	4	-40	6.0	94	2.1	1	0.3	6273	1.8	34600	-6	0.1
30-45.5647-112.4750-2-99-	0-327026	44550	-0.17	-227	73930	-8	-139	46.6	338	-2.4	2	0.8	70050	-1.6	-5409	-12	-0.2
30-45.5644-112.4744-2-99-	0-327027	62270	-0.14	-170	66510	14	347	37.6	72	-2.0	3	0.7	63230	1.4	-4213	-11	0.3
30-45.5650-112.4742-2-99-	0-327028	73290	-0.06	414	22120	57	135	6.0	11	1.9	2	0.7	14090	6.5	9346	41	0.2
30-45.5536-112.4964-2-99-	0-327029	84040	-0.10	659	14450	104	-130	9.7	64	-1.4	4	1.1	22670	11.1	21020	58	0.4
30-45.5550-112.4881-2-99-	0-327030	83580	-0.17	452	21410	105	-107	18.2	105	12.9	4	1.1	43400	6.9	20430	65	0.4
30-45.6928-110.7319-2-99-	0-327031	68650	-0.10	1394	41360	54	-93	13.6	280	-1.4	3	1.0	24630	2.9	21640	42	0.3
30-45.6894-110.7125-2-99-	0-327032	24460	-0.07	325	269300	23	-82	5.5	48	1.3	1	0.5	10280	2.4	8232	19	0.2
30-45.8700-110.6700-2-99-	0-327033	88000	-0.12	535	21140	41	-98	11.1	52	3.3	4	0.9	21170	3.0	22500	24	0.3
30-45.6850-110.6950-2-99-	0-327034	87650	-0.17	399	17540	90	-74	19.1	83	5.1	4	1.5	31030	4.1	19150	45	0.4
30-45.8700-110.5700-2-99-	0-327035	77830	-0.11	512	28220	59	-81	13.5	85	2.9	4	1.0	27930	4.3	22940	36	0.3
30-45.8786-110.8197-2-99-	0-327036	39680	-0.07	299	13970	34	-46	6.9	54	2.8	2	0.6	19380	1.9	24600	21	0.2
30-45.6875-110.6911-2-99-	0-327037	91910	-0.09	579	58020	36	808	9.6	133	-1.2	2	0.8	15110	2.2	15080	19	0.2
30-45.8791-110.9439-2-12-	0-327038	71150	-0.15	833	21950	60	-116	12.5	128	2.1	2	1.0	30490	4.4	16430	-12	0.3
30-45.8742-110.7050-2-99-	0-327039	70100	-0.10	464	63930	38	-75	8.9	41	4.0	3	0.8	19410	2.9	16180	27	0.3
30-45.6375-110.6911-2-99-	0-327040	73150	0.34	599	39400	47	-93	10.9	239	-1.3	3	0.9	30410	4.2	15640	33	0.2
30-46.1311-111.0753-2-99-	0-327041	93770	-0.11	689	44900	41	-141	11.8	15	-1.4	3	1.0	26980	2.8	14250	20	0.2
30-45.8733-110.6211-2-99-	0-327042	74410	-0.15	664	26790	58	-122	16.4	132	4.4	2	1.1	32170	2.7	19110	37	0.3
30-45.6875-110.6911-2-99-	0-327043	70040	-0.11	1660	38610	58	-102	16.2	220	-1.4	3	1.0	30190	4.3	17220	43	0.3
30-45.6875-110.6911-2-99-	0-327044	42860	-0.14	-188	57850	69	563	35.2	737	-2.0	3	1.1	112600	5.7	-4577	46	0.7
30-45.6894-110.7125-2-99-	0-327045	71170	-0.11	671	48130	45	-103	10.5	292	-1.5	2	0.9	28320	3.9	13150	24	0.4
30-45.7481-110.7473-2-99-	0-327046	69210	-0.13	1073	84440	49	-114	12.7	216	-1.8	2	1.1	24010	2.8	15360	36	0.2
30-45.8828-110.8744-2-12-	0-327047	63730	-0.12	834	36510	48	-103	15.0	408	2.3	3	1.0	37030	3.3	12290	31	0.3
30-45.8375-110.6175-2-99-	0-327048	78310	-0.09	1135	32720	50	-83	12.7	132	2.1	3	1.1	26900	3.9	17730	36	0.3
30-45.8875-110.6175-2-99-	0-327049	8320	-0.05	-173	349500	7	-96	3.5	-5	-0.6	-1	0.3	3562	-0.5	-3671	-4	-0.1
30-45.8828-110.8267-2-99-	0-327050	75270	-0.10	1110	43420	41	-102	10.9	168	-1.4	2	0.9	20890	2.5	16030	22	0.2
30-45.8719-110.6894-2-99-	0-327051	69420	-0.14	386	86860	61	-98	11.1	66	3.9	3	1.1	21700	3.7	17510	37	0.4

ELEMENTAL CONCENTRATIONS DETERMINED BY NEUTRON ACTIVATION ANALYSIS (continued)

Concentrations reported in weight parts per million (ppm)

DOE SAMPLE NUMBER (State-Latitude-Longitude-DOE Lab-Sample Type-Replicate)	LAS. SAMPLE LOCATION NUMBER	Mg	Mn	Na	Rb	Sb	Sc	Sm	Sr	Ta	Tb	Th	Ti	V	Yb	Zn	U/Th RATIO
30-45.5683-112.4872-2-99-	0-327001	55870	1374	12740	-27	-4	32.9	4.4	-454	-1	-1	-12.1	13660	313	3.9	-37	
30-45.5683-112.4881-2-99-	0-327002	33600	447	14970	118	-5	18.7	16.9	-325	-1	-2	41.6	6598	131	8.5	-25	0.139
30-45.5678-112.4878-2-99-	C-327003	22770	317	19390	73	-3	10.9	3.8	-254	-1	-1	11.6	3841	79	-1.5	86	0.200
30-45.5647-112.4939-2-99-	0-327004	392900	758	1016	-26	-4	23.6	-0.8	-332	-1	-1	-1.4	2400	109	-2.2	85	
30-45.5647-112.4925-2-99-	0-327005	-5746	644	40570	67	-2	3.1	4.5	-419	2	1	6.4	-997	-10	4.1	51	0.175
30-45.5639-112.4917-2-99-	0-327006	41590	807	13310	103	-5	23.3	7.8	-382	-1	-2	26.0	5874	145	8.3	-55	0.083
30-45.5631-112.4911-2-99-	0-327007	56390	1255	7313	-25	-5	40.9	3.6	-370	-1	-1	-13.6	11470	307	-2.4	-36	
30-45.5644-112.4900-2-99-	0-327008	113800	1411	7575	-26	-5	40.7	-0.9	-392	-1	2	-1.5	3297	240	-8.9	-38	
30-45.5664-112.4839-2-99-	0-327009	201200	352	4383	36	-3	3.6	4.0	-301	-1	-1	36.0	1151	13	4.0	69	0.343
30-45.5650-112.4839-2-99-	0-327010	5372	176	286	-39	-4	4.4	-0.9	-144	-1	-1	-1.3	-355	28	-2.3	47	
30-45.5653-112.4847-2-99-	0-327011	5066	300	294	-29	4	8.0	4.7	-183	-1	-1	11.3	2437	161	-1.9	144	0.458
30-45.5661-112.4850-2-99-	0-327012	3914	393	558	34	53	3.8	3.5	-184	-1	-1	5.9	1277	66	-1.5	395	1.300
30-45.5703-112.4861-2-99-	0-327013	33650	1175	7429	-26	-4	32.4	-0.8	-399	-1	-1	-1.5	1923	177	-2.3	-37	
30-45.5697-112.4942-2-99-	0-327014	176100	1158	4785	-42	-6	32.1	-1.5	-430	-1	-1	-2.1	5253	237	-3.5	-69	
30-45.5636-112.4817-2-99-	0-327015	71910	1075	12480	-24	-4	24.2	2.5	-358	-1	-1	1.7	5628	202	-1.9	65	0.235
30-45.5536-112.4319-2-99-	0-327016	11410	1293	11700	-22	-3	15.5	12.3	-369	1	2	17.0	4551	-9	14.0	69	0.189
30-45.5686-112.4822-2-99-	0-327017	56890	1100	13450	-25	-4	23.6	4.0	-403	-1	1	4.2	6591	248	-3.1	-32	0.264
30-45.5686-112.4825-2-99-	0-327018	-4416	1000	14830	57	-4	14.9	8.9	-399	-1	1	17.2	4257	-9	11.5	-43	0.152
30-45.5692-112.4819-2-99-	C-327019	9761	315	16980	67	-2	4.4	2.6	-235		-1	13.1	1637	32	2.3	44	0.139
30-45.5689-112.4806-2-99-	0-327020	48730	1629	12950	-27	-5	41.9	2.4	-424	-1	-1	-1.4	5804	329	2.7	-37	
20-45.5689-112.4803-2-99-	0-327021	9115	249	21450	42	-2	2.6	2.6	-263	-1	-1	11.8	1427	30	1.8	54	0.171
30-45.5675-112.4792-2-99-	0-327022	59450	1236	13770	-44	-7	37.4	2.6	-474	-1	-1	2.5	3600	229	-3.8	-70	0.220
30-45.5675-112.4789-2-99-	0-327023	90230	1309	5127	-26	-4	36.7	-0.8	-370	-1	-1	-1.4	1533	193	-2.3	-36	
30-45.5669-112.4736-2-99-	C-327024	60110	56	1027	44	-2	3.5	5.3	-145	-1	-1	18.6	2448	31	2.7	51	0.083
30-45.5592-112.4736-2-99-	0-327025	67520	154	2395	58	-2	5.8	0.5	-198	-1		1.9	3861	95	-1.4	-58	0.332
3C-45.5647-112.4750-2-99-	0-327026	63370	1874	9455	-40	-6	33.6	-1.3	-540	-1	-1	-1.9	3176	193	-3.3	-62	
30-45.5644-112.4744-2-99-	0-327027	54610	1401	14910	-28	-5	42.2	2.3	-418	-1	-1	-1.5	6634	336	3.0	-42	
30-45.5650-112.4742-2-99-	0-327028	9114	258	28100	-13	-2	3.5	3.5	569		-1	10.7	2448	34	2.6	-51	0.068
30-45.5536-112.4864-2-99-	0-327029	23530	502	32510	38	-3	11.1	5.2	-379	-1	-1	18.0	4589	98	3.7	-26	0.374
30-45.5550-112.4881-2-99-	0-327030	35950	689	17140	165	-5	21.5	5.5	-377	-1	-2	18.8	6066	155	5.0	-53	0.268
30-45.6928-110.7319-2-99-	0-327031	35470	675	15360	-20	-3	14.4	3.9	1298	-1	-1	6.0	3569	114	-2.0	84	0.332
30-45.6894-110.7125-2-99-	0-327032	14690	1071	2340	21	2	4.3	2.2	-355	-1		3.5	1636	32	1.6	65	0.357
30-45.8700-110.6700-2-99-	0-327033	33240	690	10540	41	-4	10.0	2.6	-387	-1	-1	5.4	4298	96	3.3	95	0.381
30-45.6350-110.6950-2-99-	0-327034	23370	655	3761	82	-6	13.9	5.3	-391	-1	-1	11.4	4238	124	-4.1	-57	0.261
30-45.8700-110.6700-2-99-	0-327035	33650	789	9532	57	-3	11.9	4.3	-344	-1	-1	8.1	3870	115	2.1	120	0.310
30-45.8786-110.8197-2-99-	0-327036	14230	370	3507	53	4	5.7	2.2	-204		-1	4.7	1575	60	1.8	50	0.232
30-45.6875-110.6911-2-99-	0-327037	21410	610	12860	-18	-3	8.6	1.8	-344	-1	-1	3.8	2564	74	-1.5	-26	0.439
30-45.8781-110.8439-2-12-	0-327038	19290	1112	11280	-34	-5	12.1	2.8	671	-1	-1	6.6	2920	128	-2.9	-83	0.292
30-45.8742-110.7050-2-99-	0-327039	25740	612	6427	41	-3	9.1	3.1	-311	-1	-1	6.8	3323	90	2.6	76	0.331
30-45.6875-110.6911-2-99-	0-327040	24450	740	16740	-19	-3	12.7	3.0	-325	-1	-1	6.7	3372	130	-2.3	47	0.313
30-46.1311-111.0753-2-99-	0-327041	26340	1169	23170	48	-3	11.8	3.6	1544	-1	-1	3.2	3125	123	-2.1	-26	0.400
30-45.8933-110.5711-2-99-	0-327042	30390	1053	14500	-36	-5	15.8	4.2	548	-1	-1	7.8	3021	128	-3.1	108	0.285
30-45.6875-110.6911-2-99-	0-327043	29580	891	16220	35	-3	13.0	4.3	1206	-1	-1	7.7	4648	123	-1.8	90	0.319
30-45.6875-110.6911-2-99-	0-327044	54150	1927	8341	-31	-4	29.8	5.0	-458	-1	-1	26.3	9411	531	3.4	79	0.125
30-45.6894-110.7125-2-99-	0-327045	26590	748	15260	-21	-4	13.5	4.0	-371	-1	-1	5.8	4024	145	-1.9	-21	0.386
30-45.7481-110.7478-2-99-	0-327046	23030	1064	12850	-29	-4	13.2	2.2	743	-1	-1	4.9	2747	117	-2.5	-43	0.331
30-45.8828-110.8744-2-12-	0-327047	35120	957	14390	-24	-4	15.0	3.7	633	-1	-1	6.1	5461	192	-2.3	-40	0.305
30-45.8875-110.6175-2-99-	0-327048	32520	749	13260	41	-3	12.7	4.3	1401	-1	-1	6.2	3981	117	3.0	70	0.329
30-45.8975-110.6175-2-99-	0-327049	-3405	1151	1664	-11	-1	1.0	0.6	-401	-1		-0.6	-957	46	-1.0	35	
30-45.8828-110.8267-2-99-	0-327050	27960	678	15870	-19	-3	12.7	2.3	1007	-1	-1	3.9	3190	116	-1.8	-24	0.513
30-45.8719-110.6894-2-99-	0-327051	25020	782	6645	-32	-5	10.5	4.0	-408	-1	-1	8.2	3121	93	-2.9	-106	0.323

ATTACHMENT I-2. (continued). Elemental Concentrations for Sediment Samples

DOE Sample Number: State	Latitude	Longitude	DOE Lab	Sample Type	Replicate	LASL Sample Location and Field Data: LASL Sample Location Number	Time Sampled: Date	Hour	Air Temperature	Water Temperature	Comments	Special Measurements	pH	Conductivity (µmho/cm)	Scintillometer (eU, ppm)	Rock Type	Rock Color	Sediment Type	Sediment Color	Water Flow	Water Level	Water Color	Stream Channel	Vegetation Type	Vegetation Density	Relief	Weather	Ownership	Contaminants	Well Type	Well Diameter (Inches)	Well Depth (Feet)	Water Depth (Feet)	U Concentration: Sediment Samples Analyzed by Delayed Neutron Counting (DNC), Units in ppm
30	45.6874	110.7125	2	99	0	327052	06/21/79	9	25		C				8	1	5									4	1		1					2.29
30	45.8249	110.8617	2	99	0	327053	07/25/79	11	25		C				12	1	5									4	1		1					1.81
30	45.8875	110.4175	2	99	0	327054	09/05/79	11	25		C				9	1	5									4	1		1					1.48
30	45.7019	110.8003	2	99	0	327055	09/01/79	10	25		C				9	1	5									4	3		1					2.04
30	45.8700	110.6700	2	99	0	327056	09/16/79	13	25		C				9	1	5									4	1		1					1.68
30	45.8643	110.8678	2	99	0	327057	06/17/79	13	25		C				10	1	5									4	1		1					1.55
30	45.6897	110.7097	2	99	0	327058	06/20/79	14	25		C				14	1	5									3	1		1					1.54
30	45.6994	110.7289	2	99	0	327059	07/30/79	17	25		C				14	1	5									4	1		1					2.06
30	45.7789	110.5097	2	99	0	327060	09/26/79	10	25		C				18	1	5									3	1		1					1.78
30	45.8719	110.6894	2	99	0	327061	09/16/79	14	25		C				10	1	5									3	1		1					2.32
30	45.6375	110.6911	2	99	0	327062	09/08/79	9	25		C				10	1	6									4	1		1					2.49
30	45.6375	110.6911	2	99	0	327063	09/09/79	9	25		C				13	1	6									4	1		1					2.31
30	45.4744	110.4489	2	99	0	327064	07/27/79	13	25		C					1	5									3	1		1					1.40
30	45.6750	110.7206	2	99	0	327065	06/21/79	7	25		C				16	1	8									3	1		1					0.67
30	45.7085	110.7072	2	99	0	327066	09/01/79	9	25		C				10	1	5									3	1		1					3.59
30	45.7789	110.5097	2	99	0	327067	09/26/79	10	25		C				5	1	5									3	1		1					2.03
30	45.6750	110.7206	2	99	0	327068	06/21/79	7	25		C				20	1	8									3	1		1					0.52
30	45.7125	110.7300	2	99	0	327069	07/31/79	16	25		C				11	1	5									2	1		1					1.73
30	45.8736	110.8197	2	99	0	327070	07/25/79	11	25		C				7	1	5									4	1		1					1.89
30	46.2536	113.9003	2	99	0	327071	10/01/79	15	22		C				3	3	1							1	3	5	1		1					4.58
30	46.2531	113.9936	2	99	0	327072	10/01/79	15	22		C				7	1	1							1	3	5	1		1					1.25
30	46.2633	113.9839	2	99	0	327073	10/01/79	15	22		C				18	1	1							1	3	5	1		1					0.38
30	46.2639	113.8839	2	99	0	327074	10/01/79	15	22		C				14	1	1							1	3	5	1		1					2.43
30	46.2536	113.9003	2	99	0	327075	10/01/79	14	22		C				3	3	1							1	3	5	1		1					1.34
30	46.2564	113.9189	2	99	0	327076	10/01/79	14	22		C				13	3	1							1	3	5	1		1					0.39
30	46.2639	113.8839	2	99	0	327077	10/01/79	14	22		C				44	3	1							1	3	5	1		1					0.09
30	46.2564	113.9281	2	99	0	327078	10/01/79	13	22		C				16	3	1							1	3	5	1		1					0.54
30	46.2611	113.8775	2	99	0	327079	10/01/79	13	22		C				20	3	8							1	3	5	1		1					10.90
30	46.2611	113.8775	2	99	0	327080	10/01/79	13	22		C				20	3	5							1	3	5	1		1					2.36
30	46.2611	113.8775	2	99	0	327081	10/01/79	12	22		C				20	3	1							1	3	5	1		1					1.41
30	46.2611	113.8775	2	99	0	327082	10/01/79	12	22		C				20	3	2							1	3	5	1		1					25.15
30	46.2586	113.9078	2	99	0	327083	10/01/79	11	22		C				18	3	1							1	3	5	1		1					0.34
30	46.2617	113.8889	2	99	0	327084	10/01/79	11	22		C				0	3	8							1	3	5	1		1					0.12
30	46.2594	113.8942	2	99	0	327085	10/01/79	11	22		C				7	3	8							1	3	5	1		1					1.58
30	46.2625	113.8947	2	99	0	327086	10/01/79	10	22		C				9	3	8							1	3	5	1		1					0.95
30	46.2581	113.9114	2	99	0	327087	10/01/79	10	22		C				7	3	8							1	3	5	1		1					0.40
30	46.2581	113.8969	2	99	0	327088	10/01/79	10	22		C				11	3	8							1	3	5	1		1					0.14
30	46.2572	113.9050	2	99	0	327089	10/01/79	9	22		C				13	3	8							1	3	5	1		1					0.02
30	46.2558	113.8903	2	99	0	327090	10/01/79	9	22		C				11	3	8							1	3	5	1		1					0.70
30	46.2558	113.8906	2	99	0	327091	10/01/79	9	22		C				14	3	1							1	3	5	1		1					0.03
16	46.2297	115.4217	2	99	0	327092	07/03/79	9			C					3	1							1	3	4	1		1					1.28
16	46.2305	115.4175	2	99	0	327093	07/03/79	9			C					3	1							1	3	4	1		1					1.03
16	46.2317	115.4150	2	99	0	327094	07/03/79	8			C					3	1							1	3	4	1		1					1.13
16	46.2331	115.4106	2	99	0	327095	07/03/79	9			C					3	1							1	3	4	1		1					0.81
16	46.2342	115.4064	2	99	0	327096	07/03/79	9			C					3	1							1	3	4	1		1					1.05
16	46.2381	115.4033	2	99	0	327097	07/03/79	9			C					3	1							1	3	4	1		1					1.48
16	46.2392	115.4033	2	99	0	327098	07/03/79	9			C					3	1							1	3	4	1		1					2.85
16	46.2403	115.4033	2	99	0	327099	07/03/79	10			C					3	1							1	3	4	1		1					1.06
16	46.2419	115.4025	2	99	0	327100	07/03/79	10			C					3	1							1	3	4	1		1					1.07
16	46.2456	115.4000	2	99	0	327101	07/03/79	10			C					3	1							1	3	4	1		1					1.73
16	46.2531	115.3997	2	99	0	327102	07/03/79	11			C					3	1							1	3	4	1		1					1.92

DOE SAMPLE NUMBER (STATE-LATITUDE-LONGITUDE-DOE LAB-SAMPLE TYPE-REPLICATE)	LASL SAMPLE LOCATION NUMBER	Ag	Bi	Cd	Cu	Nb	Ni	Pb	Sn	W	Be	Li
		ELEMENTAL CONCENTRATIONS DETERMINED BY X-RAY FLUORESCENCE (Concentrations reported in weight parts per million (ppm))									ELEMENTAL CONCENTRATIONS DETERMINED BY ARC-SOURCE EMISSION SPECTROGRAPHY (Concentrations in weight ppm)	
30-45.6394-110.7125-2-99-	0-327052	-5	-5	-5	52	-20	55	6	-10	-15	2	21
30-45.8239-110.8617-2-99-	0-327053	-5	-5	-5	37	-20	47	-5	-10	-15	2	16
30-45.8875-110.6175-2-99-	0-327054	-5	-5	-5	47	-20	57	-5	-10	-15	-1	33
30-45.7019-110.8003-2-99-	0-327055	-5	-5	-5	28	-20	22	5	-10	-15	1	15
30-45.8700-110.6700-2-99-	0-327056	-5	11	-5	23	-20	48	-5	-10	-15	-1	32
30-45.8643-110.8673-2-99-	0-327057	-5	-5	-5	41	-20	82	-5	-10	-15	-1	33
30-45.6837-110.7037-2-99-	0-327058	-5	-5	-5	33	-20	84	-5	-10	-15	1	30
30-45.6934-110.7280-2-99-	0-327059	-5	-5	-5	31	-20	29	-5	-10	-15	-1	25
30-45.7789-110.5097-2-99-	0-327060	-5	-5	-5	34	-20	45	10	-10	-15	-1	22
30-45.8713-110.6894-2-99-	0-327061	-5	-5	-5	77	-20	17	6	-10	-15	1	15
30-45.6875-110.6911-2-99-	0-327062	-5	10	-5	34	-20	31	-5	-10	-15	-1	25
30-45.6975-110.6911-2-99-	0-327063	-5	5	-5	31	-20	43	9	-10	-15	2	12
30-45.8744-110.8440-2-99-	0-327064	-5	-5	-5	25	24	25	-5	-10	-15	-1	20
30-45.6950-110.7206-2-99-	0-327065	-5	-5	-5	12	-20	-15	-5	-10	-15	-1	-1
30-45.7036-110.7072-2-99-	0-327066	-5	-5	-5	33	26	28	-5	-10	-15	2	61
30-45.7789-110.5097-2-99-	0-327067	-5	-5	-5	34	-20	54	-5	-10	-15	1	27
30-45.6950-110.7206-2-99-	0-327068	-5	-5	-5	22	-20	-15	-5	-10	-15	-1	2
30-45.7135-110.7300-2-99-	0-327069	-5	-5	-5	39	-20	52	5	-10	-15	-1	53
30-45.8745-110.8197-2-99-	0-327070	-5	-5	-5	42	-20	-15	-5	-10	-15	1	18
30-46.2636-113.9003-2-99-	0-327071	-5	6	-5	16	-20	-15	6	-10	-15	2	67
30-46.2631-113.8836-2-99-	0-327072	-5	-5	-5	20	-20	33	-5	-10	-15	-1	2
30-46.2633-113.8839-2-99-	0-327073	-5	-5	-5	17	-20	24	-5	-10	-15	2	4
30-46.2639-113.8839-2-99-	0-327074	-5	-5	5	79	-20	-15	-5	-10	-15	2	86
30-46.2636-113.9003-2-99-	0-327075	-5	-5	-5	44	32	-15	-5	-10	-15	-1	5
30-46.2564-113.9189-2-99-	0-327076	-5	-5	-5	18	21	-15	-5	-10	-15	-1	-1
30-46.2639-113.8839-2-99-	0-327077	-5	-5	-5	48	-20	-15	6	-10	-15	-1	2
30-46.2564-113.9281-2-99-	0-327078	-5	6	-5	58	-20	-15	-5	-10	-15	-1	-1
30-46.2611-113.8775-2-99-	0-327079	-5	-5	-5	165	-20	-15	-5	16	-15	-1	-1
30-45.2611-113.8775-2-99-	0-327080	-5	-5	-5	64	23	-15	-5	-10	39	3	4
30-46.2611-113.8775-2-99-	0-327081	-5	-5	-5	58	27	-15	-5	-10	-15	1	2
30-46.2611-113.8775-2-99-	0-327082	-5	8	-5	-10	60	-15	-5	54	-15	6	-1
30-46.2586-113.9078-2-99-	0-327083	-5	5	-5	26	-20	-15	-5	-10	-15	-1	-1
30-46.2617-113.8889-2-99-	0-327084	-5	-5	-5	117	-20	-15	-5	-10	-15	1	2
30-46.2594-113.8942-2-99-	0-327085	-5	-5	-5	310	66	-15	-5	13	-15	-1	-1
30-46.2625-113.8847-2-99-	0-327086	-5	-5	5	153	-20	45	-5	-10	-15	-1	48
30-46.2581-113.9114-2-99-	0-327087	-5	-5	-5	125	-20	-15	-5	-10	-15	-1	53
30-46.2541-113.8969-2-99-	0-327088	-5	-5	-5	154	-20	39	-5	-10	-15	-1	34
30-46.2572-113.9050-2-99-	0-327089	-5	6	5	21	-20	18	-5	-10	-15	-1	-1
30-46.2558-113.8903-2-99-	0-327090	-5	-5	-5	26	41	-15	-5	-10	-15	-1	2
30-46.2558-113.9806-2-99-	0-327091	-5	-5	-5	25	32	-15	-5	-10	-15	-1	-1
16-46.2297-115.4217-2-99-	0-327092	-5	-5	-5	22	-20	-15	9	-10	-15	1	11
16-46.2306-115.4175-2-99-	0-327093	-5	-5	-5	17	-20	-15	10	-10	-15	2	9
16-46.2317-115.4150-2-99-	0-327094	-5	5	-5	29	-20	-15	11	-10	-15	2	11
16-46.2331-115.4106-2-99-	0-327095	-5	-5	-5	33	-20	-15	7	-10	-15	2	8
16-46.2342-115.4064-2-99-	0-327096	-5	-5	-5	25	-20	-15	24	-10	-15	-1	14
16-46.2381-115.4033-2-99-	0-327097	-5	-5	-5	22	-20	-15	23	-10	-15	1	10
16-46.2392-115.4033-2-99-	0-327098	-5	-5	-5	34	-20	-15	9	-10	-15	3	13
16-46.2403-115.4033-2-99-	0-327099	-5	-5	-5	34	-20	-15	9	-10	-15	3	10
16-46.2419-115.4025-2-99-	0-327100	-5	6	-5	17	-20	-15	8	-10	-15	1	13
16-46.2456-115.4000-2-99-	0-327101	-5	-5	-5	17	-20	-15	10	-10	-15	3	18
16-46.2531-115.3997-2-99-	0-327102	-5	-5	-5	27	-20	-15	10	-10	-15	3	19

ATTACHMENT-2. (continued). Elemental Concentrations for Sediment Samples

ELEMENTAL CONCENTRATIONS DETERMINED BY NEUTRON ACTIVATION ANALYSIS

Concentrations reported in weight parts per million (ppm)

DOE SAMPLE NUMBER (STATE-LATITUDE-LONGITUDE-DOE LAB-SAMPLE TYPE-REPLICATE)	LASL SAMPLE LOCATION NUMBER	Al	Au	Ba	Ca	Ce	Cl	Co	Cr	Cs	Dy	Eu	Fe	Hf	K	La	Lu
30-45.6894-110.7125-2-99-	0-327052	71540	-0.10	1967	34370	48	-96	14.4	219	-1.4	3	1.0	26510	3.4	16970	32	0.2
30-45.8289-110.8617-2-99-	0-327053	71100	-0.10	1558	46790	45	-93	12.5	230	-1.5	3	1.2	28990	3.4	15150	35	-0.1
30-45.8975-110.6175-2-99-	0-327054	65580	-0.11	1127	57490	38	-110	12.2	216	-1.5	2	0.9	23210	2.5	15680	22	0.2
30-45.7019-110.8003-2-99-	0-327055	69100	-0.13	926	40100	57	-109	8.4	178	-1.7	2	0.9	25480	3.2	17940	32	0.3
30-45.8700-110.6700-2-99-	0-327056	68810	-0.07	702	55480	34	-95	13.4	232	-1.3	3	0.9	28720	3.6	14540	27	0.3
30-45.8583-110.8679-2-99-	0-327057	56300	-0.13	868	74360	55	-91	19.1	551	-1.9	4	1.1	35600	2.8	9832	32	-0.5
30-45.6897-110.7097-2-99-	0-327058	54400	-0.12	1050	73070	36	-104	14.6	445	-1.7	3	0.9	26520	2.7	8160	28	0.2
30-45.6994-110.7289-2-99-	0-327059	65550	-0.14	1230	54420	70	-113	12.7	232	-1.9	2	1.1	28780	3.7	15230	39	-0.2
30-45.7739-110.5097-2-99-	0-327060	68830	-0.10	1427	53360	43	-104	12.1	175	-1.3	3	1.0	26300	4.0	14420	25	0.2
30-45.8719-110.6894-2-99-	0-327061	77810	-0.10	1309	37640	65	-96	12.7	129	-1.4	4	1.5	27730	2.9	17650	42	0.3
30-45.6475-110.6911-2-99-	0-327062	57130	-0.11	463	71290	52	-103	11.2	297	-1.5	3	1.0	34640	5.5	9070	34	0.3
30-45.6475-110.6911-2-99-	0-327063	77950	-0.13	1594	29380	69	-125	12.2	143	-1.8	3	1.2	26860	3.9	18170	41	0.2
30-45.8744-110.8489-2-99-	0-327064	73540	-0.09	1303	50850	42	-95	11.2	105	-1.3	3	1.1	25500	3.1	14920	23	0.3
30-45.6950-110.7206-2-99-	0-327065	6242	-0.05	-175	347400	11	-95	2.9	9	-0.6	-1	0.3	3440	-0.5	-4047	-5	-0.1
30-45.7046-110.7072-2-99-	0-327066	52000	-0.09	1150	120900	34	-112	10.1	103	2.3	2	0.8	18230	2.7	17020	24	0.2
30-45.7707-110.5097-2-99-	0-327067	64000	-0.17	334	50800	55	-122	17.1	439	-2.3	3	1.3	51050	4.6	-4504	34	-0.2
30-45.6950-110.7206-2-99-	0-327068	4881	-0.04	-177	347200	9	-97	3.7	20	-0.5	1	0.3	3668	-0.4	-4139	-5	-0.1
30-45.7125-110.7300-2-99-	0-327069	59680	-0.10	936	92290	41	-98	11.6	211	2.0	2	1.1	26320	2.9	15010	29	0.2
30-45.8736-110.8197-2-99-	0-327070	73330	-0.12	1389	41670	46	-107	13.8	177	-1.7	3	1.0	25990	2.3	17530	34	0.4
30-46.2636-113.9003-2-99-	0-327071	79100	-0.10	926	5706	88	226	2.8	-9	6.0	2	1.1	9781	7.1	35470	51	0.4
30-46.2631-113.8836-2-99-	0-327072	23820	-0.08	-149	141900	20	-99	11.3	56	-1.1	4	0.9	34400	2.7	-3643	7	0.6
30-46.2533-113.8339-2-99-	0-327073	15900	-0.08	-203	111200	48	-151	13.2	35	-1.1	1	1.2	51740	4.0	-5433	24	0.3
30-46.2639-113.8939-2-99-	0-327074	33050	-0.07	-111	100200	41	107	6.7	41	-1.0	4	0.6	13170	5.0	14690	20	0.3
30-46.2636-113.9003-2-99-	0-327075	71230	-0.11	10860	25930	195	-125	7.3	-11	-1.5	5	3.0	34190	4.4	52640	125	0.6
30-46.2564-113.9189-2-99-	0-327076	100300	-0.05	9608	3544	20	192	2.9	-5	-0.5	1	0.7	5199	1.3	79960	17	-0.1
30-46.2639-113.8939-2-99-	0-327077	132500	-0.04	5305	3137	3	377	2.0	-4	-0.4	-1	0.3	1534	1.2	76600	-4	-0.1
30-46.2564-113.9281-2-99-	0-327078	70340	-0.05	16910	15350	49	-107	3.8	-7	-0.8	5	1.5	12260	3.4	56490	31	0.5
30-46.2511-113.8775-2-99-	0-327079	20410	0.71	-1026	187500	154	-452	4.7	26	-2.5	65	20.6	107200	26.1	-22870	36	9.4
30-46.2611-113.8775-2-99-	0-327080	10830	-0.11	-370	65750	93	-346	23.4	-10	-1.5	-2	2.6	68710	7.2	-11540	40	0.7
30-46.2611-113.8775-2-99-	0-327081	103400	-0.05	5761	19380	78	189	3.3	-6	-0.6	3	1.6	5477	1.6	16510	45	0.2
30-46.2611-113.8775-2-99-	0-327082	9154	1.49	-191	172500	1752	317	3.5	43	-1.8	123	41.2	8516	41.7	-2839	707	2.7
30-46.2586-113.9078-2-99-	0-327083	2025	-0.17	-144	153300	312	318	2.1	-16	-2.4	5	3.8	21390	-1.5	-2725	185	0.2
30-46.2517-113.8887-2-99-	0-327084	17160	-0.11	-221	135800	24	-139	16.0	53	-1.5	3	1.4	51910	2.9	-5573	-7	0.3
30-46.2594-113.8942-2-99-	0-327085	20840	0.22	-258	100100	200	-169	58.9	-12	-2.0	11	7.3	113400	6.0	-6663	70	0.6
30-46.2625-113.8847-2-99-	0-327086	34580	-0.19	1223	111400	19	230	29.5	122	-2.6	2	1.3	30740	-1.6	19200	-12	-0.2
30-46.2581-113.9114-2-99-	0-327087	27210	-0.26	742	116800	23	301	32.3	-23	-3.6	-1	1.4	56080	-2.2	11170	-17	-0.3
30-46.2581-113.8962-2-99-	0-327088	59910	-0.16	4618	45950	18	210	50.7	195	3.7	1	1.7	55950	-1.3	38490	-12	-0.2
30-46.2572-113.9050-2-99-	0-327089	79420	-0.15	2656	21390	-6	132	66.2	-14	-2.3	-1	1.6	55000	-1.4	17650	-12	-0.2
30-46.2558-113.8903-2-99-	0-327090	12330	-0.11	-278	123300	39	-184	13.8	40	-1.5	-1	1.1	50290	2.4	-6986	18	-0.1
30-46.2558-113.8805-2-99-	0-327091	-1911	-0.19	-243	363200	22	256	2.5	-17	-2.6	8	1.7	5029	-1.6	-5290	-14	1.4
16-46.2277-115.4217-2-99-	0-327092	79920	-0.05	1442	13140	115	-92	3.6	-5	-0.6	2	0.8	6048	5.3	28780	67	-0.1
16-46.2306-115.4175-2-99-	0-327093	90530	-0.06	952	20630	73	-104	4.8	-6	-0.8	3	1.0	13600	5.1	13500	42	0.2
16-46.2317-115.4150-2-99-	0-327094	95040	-0.06	1802	17100	83	-109	3.4	-6	-0.7	2	0.8	7693	4.4	24440	57	0.3
16-46.2331-115.4106-2-99-	0-327095	79130	-0.07	1736	16010	94	-111	1.8	-7	-0.9	-1	1.0	8454	3.9	21830	51	-0.1
16-46.2342-115.4064-2-99-	0-327096	76060	-0.06	1690	10910	82	-84	4.2	-5	-0.7	3	0.8	6072	3.9	35400	48	0.2
16-46.2381-115.4033-2-99-	0-327097	76670	-0.05	1350	9377	65	-86	1.9	-4	-0.6	2	0.5	5340	3.1	33050	41	0.3
16-46.2392-115.4033-2-99-	0-327098	85640	-0.07	1634	18920	96	-129	3.0	-7	-0.8	-1	1.2	11910	4.6	15850	65	0.3
16-46.2403-115.4033-2-99-	0-327099	77630	-0.04	1597	14010	33	-93	2.8	-4	0.8	2	0.7	4077	1.8	23170	22	0.2
16-46.2419-115.4025-2-99-	0-327100	77830	-0.05	1154	15460	44	-94	2.6	-5	-0.6	2	0.8	5565	3.3	17340	22	0.2
16-46.2456-115.4000-2-99-	0-327101	76500	-0.05	1044	13250	54	-104	3.2	-5	-0.6	3	0.7	4327	2.5	27020	37	0.3
16-46.2531-115.3997-2-99-	0-327102	79340	-0.07	954	13060	83	-115	2.1	-7	-0.9	3	0.7	6632	[illegible]	[illegible]	[illegible]	[illegible]

ELEMENTAL CONCENTRATIONS DETERMINED BY NEUTRON ACTIVATION ANALYSIS (continued)

Concentrations reported in weight parts per million (ppm)

DOE SAMPLE NUMBER (STATE-LATITUDE-LONGITUDE-DOE LAB-SAMPLE TYPE-REPLICATE)	LASL SAMPLE LOCATION NUMBER	Mg	Mn	Na	Rb	Sb	Sc	Sm	Sr	Ta	Tb	Th	Ti	V	Yb	Zn	U/Th RATIO
30-45.6894-110.7125-2-99-	0-327052	31130	930	15230	32	-3	13.6	4.6	1616	-1	-1	6.1	3557	118	3.3	93	0.375
30-45.8249-110.8617-2-99-	0-327053	34430	926	13380	-21	-3	15.6	3.9	1151	-1	-1	6.2	3580	124	2.7	76	0.292
30-45.8875-110.6175-2-99-	0-327054	35630	861	15170	31	106	12.1	2.5	2280	-1	-1	4.4	3287	128	2.0	-10	0.336
30-45.7019-110.8003-2-99-	0-327055	24500	570	17030	-30	-4	11.2	2.7	689	-1	-1	6.1	3042	112	-2.2	-42	0.334
30-45.8700-110.6700-2-99-	0-327056	37450	912	15430	-19	-3	13.1	3.7	-346	-1	-1	5.1	3961	130	1.7	-67	0.329
30-45.8583-110.8678-2-99-	0-327057	62610	1154	9810	-24	-4	33.4	3.8	1674	-1	-1	5.0	3955	174	-9.4	-34	0.310
30-45.6897-110.7097-2-99-	0-327058	43800	988	12330	-22	-4	18.5	2.4	1296	-1	-1	3.2	4287	165	-2.3	-32	0.481
30-45.6794-110.7289-2-99-	0-327059	28770	777	14610	-31	-4	13.2	3.8	1005	-1	-1	5.9	2443	118	-2.7	-46	0.349
30-45.7789-110.5097-2-99-	0-327060	31480	875	18100	-19	-3	12.2	3.2	1517	-1	-1	4.8	3809	114	2.4	69	0.371
30-45.8719-110.6974-2-99-	0-327061	24490	945	15390	36	-3	13.4	5.4	1707	-1	-1	6.9	4184	124	2.6	86	0.336
30-45.6875-110.6911-2-99-	0-327062	28210	950	12790	-22	-3	12.7	3.0	-391	-1	-1	7.6	4401	176	1.8	85	0.328
30-45.6875-110.6311-2-99-	0-327063	18950	734	19200	-31	-4	11.1	2.9	1325	-1	-1	7.2	3548	92	-3.0	-44	0.321
30-45.8744-110.8483-2-99-	0-327064	25550	959	13890	24	-3	11.8	3.5	2719	-1	-1	4.0	3744	110	-1.9	79	0.350
30-45.6750-110.7205-2-99-	0-327065	-3765	1611	1219	-10	-1	1.1	-0.4	-424			0.7	-984	25	-0.9	41	0.957
30-45.7086-110.7072-2-99-	0-327066	19950	1317	9216	-19	-3	7.2	2.4	865	-1	-1	5.6	2263	117	2.5	83	0.641
30-45.7737-110.5077-2-99-	0-327067	43350	1075	16180	-39	-5	22.6	3.4	-455	-1	-1	6.2	4772	196	-3.2	-54	0.327
30-45.6950-110.7206-2-99-	0-327068	-3775	1606	1042	-10	-1	1.2	0.9	-433			0.6	-1013	39	-2.7	-27	0.367
30-45.7125-110.7300-2-99-	0-327069	32530	1032	12730	-20	-3	13.1	3.2	954	-1	-1	6.2	3584	116	-1.8	77	0.279
30-45.8755-110.8197-2-99-	0-327070	29190	998	12760	-23	-4	14.5	2.7	1547	-1	-1	3.7	4061	159	-2.1	-33	0.511
30-46.2636-113.9003-2-99-	0-327071	-4440	104	24620	84	-3	5.0	6.3	-272	-1	-1	19.8	1322	-7	-1.7	86	0.231
30-46.2631-113.8836-2-99-	0-327072	89900	1356	9165	-17	-3	14.2	4.3	-372		1	3.8	3323	175	4.3	75	0.337
30-46.2533-113.8839-2-99-	0-327073	45010	2268	8751	-18	-2	11.7	4.5	-517	1	1	3.3	2119	224	3.2	67	0.267
30-46.2539-113.8839-2-99-	0-327074	82240	423	11100	23	-2	10.5	4.0	-250		1	3.9	3384	63	3.0	-20	0.636
30-46.2536-113.9003-2-99-	0-327075	-5265	1236	15620	66	-3	8.3	10.2	5111	-1	-1	15.9	4961	237	4.5	-36	0.084
30-46.2564-113.9189-2-99-	0-327076	3370	114	20130	55	-1	1.1	2.1	6451			1.5	825	47	-0.9	-12	0.260
30-46.2619-113.8833-2-99-	0-327077	-3673	42	26320	68	-1	0.3	-0.4	8088			-0.5	-526	-6	-0.7	-18	
30-46.2554-113.9281-2-99-	0-327078	-4255	694	19270	45	-2	1.7	5.3	6745	-1	1	2.2	2357	166	4.4	44	0.245
30-46.2611-113.8775-2-99-	0-327079	-22150	8610	1332	-44	-6	22.5	70.0		-2	13	7.9	11970	1122	78.2	-62	1.380
30-46.2611-113.6775-2-99-	0-327080	23240	3910	6009	-24	-3	19.3	11.2	-998	1	1	4.6	-2257	134	5.5	112	0.513
30-46.2611-113.8775-2-99-	0-327081	-5573	314	53740	24	-1	0.9	6.6	8319	2		5.2	2366	24	-0.9	-15	0.271
30-46.2611-113.8775-2-99-	0-327082	-3331	557	1092	-32	9	1.2	255.5	1510	61	19	68.4	99998	670	33.7		0.368
30-46.2536-113.9078-2-99-	0-327083	86500	714	475	-35	-6	32.7	16.2	-319	-1	-1	11.9	-744	63	-3.9	-55	0.029
30-46.2617-113.8083-2-99-	0-327084	84250	2449	4560	-23	-3	22.8	6.1	-564	-1	-1	-1.2	5203	252	2.0	54	
30-46.2594-113.8942-2-99-	0-327085	38550	2243	4753	-32	-5	30.5	45.4	-645	4	4	5.8	17670	548	6.2	-43	0.290
30-46.2625-113.8847-2-99-	0-327086	128300	1049	5928	-32	-6	45.0	1.7	-439	-1	-1	-1.9	5920	168	-3.5	-48	
30-46.2581-113.9114-2-99-	0-327087	131300	1726	7595	-53	-9	63.0	4.4	-557	-2	-2	-2.7	4647	259	-4.9	-86	
30-46.2581-113.8967-2-99-	0-327088	152300	1471	2477	117	-5	26.5	2.2	-492	-1	-1	-1.7	10890	222	-3.1		
30-46.2572-113.9050-2-99-	0-327089	53500	948	917	-39	-5	14.9	-1.0	-423	-1	-1	-1.7	11250	201	-3.0	111	
30-46.2558-113.8903-2-99-	0-327090	48530	2748	4945	-23	-3	14.1	4.0	-704	-1	-1	1.6	3153	231	-2.0	85	
30-46.2558-113.9906-2-99-	0-327091	-4945	1835	292	-35	-6	31.1	5.8	821	-1	-2	-2.1	-1322	-13	10.5	-62	
16-46.2297-115.4217-2-99-	0-327092	-3770	115	29460	36	-1	1.7	5.9	545			19.4	741	9	2.1	42	
16-46.2306-115.4175-2-99-	0-327093	10280	218	30540	38	-2	3.7	4.7	486	-1	-1	9.0	2066	37	2.0	66	
16-46.2317-115.4150-2-99-	0-327094	-4438	140	29710	28	-2	1.1	2.9	1285			9.3	1777	23	-1.2	57	
16-46.2331-115.4106-2-99-	0-327095	-4699	170	27990	51	-2	1.6	2.7	738	-1		7.2	1073	14	-1.4	69	
16-46.2342-115.4064-2-99-	0-327096	6100	103	21900	54	-2	2.7	5.8	397	-1		14.7	1104	15	2.4	44	
16-46.2381-115.4033-2-99-	0-327097	-3563	98	26760	53	-1	1.6	4.2	441			10.8	703	-6	-0.9	47	
16-46.2392-115.4033-2-99-	0-327098	-5244	372	33730	28	5	1.3	4.9	962	-1	-1	13.5	1844	13	-1.3	59	
16-46.2403-115.4033-2-99-	0-327099	-3830	163	28970	49	-1	1.4	2.3	617			5.6	-577	-6	1.6	40	
16-46.2419-115.4025-2-99-	0-327100	-3805	146	29000	35	-2	2.1	3.0	680			6.4	1120	11	1.9	39	
16-46.2456-115.4000-2-99-	0-327101	-4234	122	29440	49	-2	1.5	2.8	524			7.6	821	9	1.8	30	
16-46.2531-115.3997-2-99-	0-327102	-4855	112	31920	48	-2	2.5	1.7	627	-1	-1	10.3	960	-7	-1.4	72	